

20030228062



US Army Corps  
of Engineers  
Construction Engineering  
Research Laboratories

AD-A276 875



USACERL Technical Report EP-93/06  
August 1993  
Stormwater Management on Military Installations

(2)

## A Summary of Best Management Practices for Nonpoint Source Pollution

by  
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Nonpoint source (NPS) pollution is a major pollution concern of the nation and, as point sources have become more controlled, NPS pollution is receiving increased Federal attention. The Department of Defense and the Army are following the national goals of reducing NPS pollution.

Army Regulation 200-1, *Environmental Protection and Enhancement*, requires that NPS pollution be minimized and that Army installations and major commands comply with Federal and state regulations. However, environmental managers and engineers have no concise summary of alternatives available for NPS pollution control.

This report presents a range of alternatives, both structural and nonstructural, that may be used to ensure that Army major commands and installations are able to not only comply with legislative and regulatory requirements, but also to be good neighbors and stewards of valuable resources.

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE August 1993	3. REPORT TYPE AND DATES COVERED Final		
4. TITLE AND SUBTITLE A Summary of Best Management Practices for Nonpoint Source Pollution		5. FUNDING NUMBERS 4A162720 A896 TA - NN WU - UG2		
6. AUTHOR(S) Richard J. Scholze and Mark P. McNeilly				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Construction Engineering Research Laboratories (USACERL) P.O. Box 9005 Champaign, IL 61826-9005		8. PERFORMING ORGANIZATION REPORT NUMBER TR EP-EP-93/06		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Center for Public Works (USACPW) ATTN: CECPW-FU-S Bldg 358 Fort Belvoir, VA 22060-5516		10. SPONSORING/MONITORING AGENCY REPORT NUMBER		
11. SUPPLEMENTARY NOTES  Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.		12b. DISTRIBUTION CODE		
13. ABSTRACT (Maximum 200 words)  Nonpoint source (NPS) pollution is a major pollution concern of the nation and, as point sources have become more controlled, NPS pollution is receiving increased Federal attention. The Department of Defense and the Army are following the national goals of reducing NPS pollution.  Army Regulation 200-1, <i>Environmental Protection and Enhancement</i> , requires that NPS pollution be minimized and that Army installations and major commands comply with Federal and state regulations. However, environmental managers and engineers have no concise summary of alternatives available for NPS pollution control.  This report presents a range of alternatives, both structural and nonstructural, that may be used to ensure that Army major commands and installations are able to not only comply with legislative and regulatory requirements, but also to be good neighbors and stewards of valuable resources.				
14. SUBJECT TERMS nonpoint source (NPS) pollution Best Management Practices (BMPs) environmental compliance		15. NUMBER OF PAGES 102		
		16. PRICE CODE		
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT SAR	

## FOREWORD

This research was conducted for the U.S. Army Center for Public Works (USACPW) under project 4A162720A896, "Base Facility Environmental Quality"; Task Area NN; Work Unit UG2, "Stormwater Management on Military Installations." The technical monitor was Malcolm McLeod, CECPW-FU-S.

This research was performed by the Environmental Engineering Division (EP), Environmental Sustainment Laboratory (EL), U.S. Army Construction Engineering Research Laboratories (USACERL). Dr. Edgar D. Smith is Acting Chief, CECER-EP and William D. Goran is Acting Chief CECER-EL. The USACERL technical editor was Gloria J. Wienke, Information Management Office.

Appreciation is expressed to the following reviewers: Bob Fenlason CECPW-FU and Ron Nichols, FORSCOM HQ-EN.

LTC David J. Rehbein is Commander of USACERL and Dr. L.R. Shaffer is Director.

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## **A SUMMARY OF BEST MANAGEMENT PRACTICES FOR NONPOINT SOURCE POLLUTION**

### **1 INTRODUCTION**

#### **Background**

Nonpoint source (NPS) pollution typically is defined as pollution that originates from sources that are diffuse and difficult to pinpoint. In contrast to point source pollution (such as wastewater effluent outfalls), NPS pollution is highly variable in quantity and character and is affected by human alterations to the landscape and the watershed hydrology of an area. Nonpoint source pollution is an umbrella term that includes storm sewer drainage containing a variety of contaminants from heavy metals to petroleum products, agricultural runoff, erosion and sedimentation, atmospheric deposition such as acid rain, chemical and fuel spills, and other pollutants running off large land areas. Other contaminants such as nutrients (nitrogen and phosphorous), toxic substances, pesticides, pathogens, and organics can be water-borne and are also considered NPS pollution.

NPS pollution is most commonly triggered by precipitation and snowmelt and its effects appear downgradient from the source. Pollutant loadings are related to precipitation volume and intensity, duration, infiltration, and other hydrologic parameters.

NPS pollution is typically identified in two major categories, rural and urban, which translate to noncantonment and cantonment for the Army. Noncantonment would include activities such as training areas, firing ranges, agricultural and silvicultural activities, etc. The cantonment area would more closely parallel urban runoff from roads and highways, landscaped areas (fertilizers and herbicides), construction sites, and industrial sources such as motor pools, coal piles, landfills, etc.

NPS pollution can cause both water quantity problems (too much, too little, or availability not meeting demand) and quality problems (bad odor or appearance, fish kills, impaired use, high chemical levels, high sediment levels).

Land use within a drainage area has the dominant role in determining water quality degradation caused by NPS pollutants. NPS discharges collected at a single point and then discharged (such as a storm sewer outfall) may be classified as a point source. The most common Army nonpoint sources of pollution include:

- Training areas and impact zones discharging runoff containing sediment, nutrients, and hazardous materials,
- Agricultural and rangeland leases discharging runoff containing sediment, nutrients, pesticides, and bacteria,
- Construction areas discharging runoff containing sediment and other materials,
- Industrial areas discharging runoff containing oil, grease, and other hazardous materials,

- Residential and commercial areas discharging runoff containing oil and grease, sediments, nutrients, pesticides, and hazardous materials, and
- Contaminated groundwater and surface runoff from past and present disposal areas.

NPS pollution has not been as effectively controlled to date as has point source pollution. It cannot be measured as directly and violators (polluters) may not be easy to ascertain or locate. Loadings and pollutant discharges vary from month to month and are attenuated as they are transported.

States have operated various NPS programs for many years through both state and local programs. Federal environmental organizations have become increasingly concerned with and aware of the role of NPS pollution in degrading the quality of the nation's waterways, which has prompted more stringent requirements and legislation.

Because the Clean Water Act and subsequent amendments<sup>\*</sup> have mandated NPS pollution control, sources gradually are being identified and regulated. Mitigating nonpoint source pollution is rapidly becoming the nation's focal point for attaining the water quality goals of the 1987 Water Quality Act. NPS pollutants create the same types of water quality problems as point source pollutants. Over 50 percent of the pollutants remaining in our nation's waterways have been attributed to NPS pollution. Nationally, abatement costs are staggering; for example, abatement of one pollutant (sediment) accounts for \$6 billion annually.<sup>1</sup>

The Department of Defense (DoD) and the Army are following the national goals of reducing nonpoint source pollution. Army Regulation (AR) 200-1, *Environmental Protection and Enhancement*,<sup>2</sup> requires that NPS pollution control be incorporated into construction projects and that all Army facilities comply with applicable Federal and state regulations. Requirements for soil conservation and wise stewardship of natural resources also drive substantial Army programs that emphasize NPS control for training areas.

One major current Army activity results from final rules issued by the U.S. Environmental Protection Agency (USEPA) requiring application for National Pollutant Discharge Elimination System (NPDES) permits for discharges of stormwater from industrial activities and larger municipal separate storm sewer systems. The regulation, known as the Stormwater Application Rule, requires hundreds of population centers and hundreds of thousands of industries to get permits for their storm sewer discharges. This rule is expected to be the focus of activity in the near term regarding the regulation of stormwater, which is one category of nonpoint source discharges. Although Army major commands and installations are in the process of applying for NPDES stormwater permits (in compliance with existing legislation) environmental managers currently have no concise summary of alternatives available for reducing NPS pollution. This report presents a range of alternatives, both structural and nonstructural, that may be used to ensure Army major commands and installations are able to not only comply with legislative and regulatory requirements, but also to be good neighbors and stewards of valuable resources.

\* Public Law (PL) 92-500, The Federal Water Pollution Control Act Amendments of 1972 as amended, often referred to collectively as the Clean Water Act (CWA).

<sup>1</sup> Novotny, Vladimir, 1988, "Diffuse (Nonpoint) Pollution - A Political, Institutional, and Fiscal Problem," *Journal Water Pollution Control Federation (JWPCF)*, vol 60, no. 8 (1988), pp 1404-1413.

<sup>2</sup> Army Regulation (AR) 200-1 *Environmental Protection and Enhancement* (Headquarters, Department of the Army, 23 April 90).

### **Objective**

The objective of this research was to prepare a summary of best management practices (BMPs) that Army environmental managers may use to reduce nonpoint source pollution.

### **Approach**

Researchers compiled and summarized information about best management practices from available literature, Federal regulations, and Army policies. The result gives environmental managers an introduction to the vast array of appropriate technologies or methods that can be used to address local problems. Presentation of alternatives varies in level of detail from elaborate summaries (including design guidance) to brief listings. The listings are included to make environmental managers aware of the variety and applicability of alternatives; references to detailed information are provided. Selecting the most appropriate measures, or BMPs, will depend on land form, climate, and other local variables.

### **Mode of Technology Transfer**

It is recommended that the information in this report be included in updates to Army Regulation (AR) 200-1, *Environmental Protection and Enhancement*.

## 2 POLICIES AND REGULATIONS

### Control Efforts

Historically, efforts to control water pollution have focused on point sources, which are easier to characterize and control than nonpoint sources. Early concern over NPS pollution was directed primarily at water quantity problems such as flooding. However, NPS pollution is now recognized as a major contributor to water quality problems such as excessive sediment loadings, erosion, nutrient enrichment, and bacterial and toxic chemical contamination. Most national surveys currently identify NPS pollution as the number one cause of water quality violations and failure to achieve designated use standards. Recent studies indicate that sediment from nonpoint sources caused 42 percent of the observed impaired river miles. For lakes, 49 percent of the impaired acreage was caused by nutrients, 25 percent by sediment, and 5 percent by pesticides. These pollutants are deposited mostly by runoff waters. Damages are estimated in the billions of dollars per year.<sup>3</sup>

The many types of NPS pollution generally may be defined as either "urban" or "rural." Urban NPS pollution includes runoff from roads, parking lots, lawns, parks, combined sewer overflows, construction sites, industrial storage areas, and coal/slag piles. Rural NPS pollution includes runoff from some of the above sources plus runoff from agriculture, silviculture, feedlots, mining, and extensive areas of soil erosion. The Army must deal not only with these types of nonpoint sources, but also with many sources unique to Army activities, including intensive vehicle maintenance, troop training, tracked and wheeled vehicle exercises, equipment testing, firing ranges, and fire safety training.

Though nutrients are beneficial in proper quantities, overloads can upset the natural balance in the receiving water environment. For example, excessive nutrient loadings can lead to algal blooms, which deplete dissolved oxygen in the water and lead to fish kills. NPS runoff contains not only nutrients and particulate matter, but various toxic chemicals including metals, petroleum compounds, pesticides, and other substances, depending on its origin. Agricultural runoff (from leased Army lands) represents not only a loss of valuable topsoil, but also a potential source of undesirable nitrogen, phosphorous, and pesticides.

The primary national mandate for the control of water pollution is embodied in the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500), as subsequently amended, often referred to collectively as the Clean Water Act (CWA). The broad goals of this statute are to "restore and maintain the chemical, physical, and biological integrity of the nation's waters."

Among the primary enforcement tools of the CWA are permits issued under the NPDES program. Most NPS discharges were excluded from the NPDES program in its early years to allow primary attention to be given to point sources and waste water treatment plants. With gradual success in controlling point sources and increasing recognition of the effects of NPS pollution on water quality, attention has been shifting to designing effective national NPS pollution control programs.

One result of the shift in attention is the 1977 Surface Mining Control and Reclamation Act, which requires that runoff from mines meet point source discharge requirements. Another result is the variety of Federal, state, and local programs that help control erosion and sedimentation from agricultural

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<sup>3</sup> *Challenges for the Future*, Interim Report of the Water Quality 2000 Steering Committee (Water Pollution Control Federation, Alexandria, VA, 1991).

operations through soil and water conservation districts. The shift also lead to landfill leachate being added as a point source under the Clean Water Act.

Section 208 of the 1977 Clean Water Act required states to develop NPS pollution control plans. Slow implementation of that guidance caused the USEPA to issue a National Nonpoint Source Policy on 12 December 1984 to support and accelerate development and implementation of NPS pollution management programs. In 1987, the Water Quality Act attempted to correct the lack of implementation. This legislation requires states to assess their surface waters, identify those waters affected by NPS pollution, and develop and implement management plans to address the problems.

From 1978 through 1983, USEPA funded a set of studies collectively known as the Nationwide Urban Runoff Program (NURP). One purpose of this program was to identify the pollution content of stormwater. Runoff from residential, commercial, and light industrial areas was surveyed. The data showed that stormwater contained many of the same conventional and toxic pollutants regulated from process outfalls and publically owned treatment works (POTWs), sometimes in very high quantities.

The 1987 Act devised an implementation strategy compromise whereby USEPA would issue permits for stormwater discharges, but could focus on the most contaminated discharges first. The USEPA began issuing a number of guidance documents to regulate stormwater discharges. These rules are being promulgated and revised.

To provide a framework for an effective stormwater permitting program under the NPDES, Section 402(p) was added to the CWA. Permits would be required for discharges associated with industrial activity, municipal separate storm sewer systems serving populations of more than 100,000, and other NPS discharges that the Administrator of the USEPA or a state equivalent considered particularly significant. Permits for other types of stormwater discharges could not be required before 1 October 1992.

Section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA, PL 101-508) also applies to NPS pollution control. This Act requires the states to develop Coastal Nonpoint Pollution Control Programs, which must be approved by the National Oceanic and Atmospheric Administration (NOAA) and USEPA.

The Food Security Act of 1985 (FSA), later amended by the Food, Agricultural, Conservation, and Trade Act of 1990 (FACTA), established a conservation program to convert highly erodible croplands to less intensive uses. Millions of acres will be included under this program, which will reduce agricultural NPS pollution.

The Safe Drinking Water Act also contains provisions that may relate to NPS pollution. For example, the Act directs the states to develop Wellhead Protection Programs, which may dictate allowable land uses in the vicinity of a well used for drinking water supply. Some, but not all, of the states have submitted programs to the USEPA for approval.

### State Requirements

In addition to Federal rules, Army installations must comply with a host of state and regional requirements (e.g., the Chesapeake Bay Program). Many requirements regarding land use, and therefore relevant to NPS pollution, are developed and enforced at the state level. These programs may specify BMPs to be followed during construction and other installation activities.

## **Future Rules**

A major reauthorization by Congress of the CWA is anticipated in the next year or two. NPS control is a major issue in this reauthorization. Potential new rules are highly controversial and may be very costly, so one can expect to see much attention given to this issue before promulgation.

## **Army Policy**

NPS pollution is significant for the Army because it affects pollution prevention, conservation, and compliance—three of the four pillars (thrusts) identified by the Secretary of the Army for the Army environmental program. A policy memorandum dated 17 July 1990 issued jointly by the Secretary of the Army and the Army Chief of Staff established a top Army leadership commitment to environmental compliance. Every member of the Army can play a role in environmental protection and stewardship. All Army personnel must constantly be aware that every activity (what they do and what they avoid doing) can have an environmental impact.

Army policy regarding NPS and environmental issues is contained in AR 200-1. NPS is addressed in Chapter 3 (Water Resources Management), which states that the Army will comply with all applicable permits, will control discharges, and will demonstrate leadership in this area. Specifically, the Army will "control or eliminate runoff and erosion through sound vegetative and land management practices" and "consider NPS abatement in all construction, installation operations, and land management plans and activities."<sup>4</sup>

Section 1-42, part j of AR 200-1 states that "an integrated, multi-use, natural resource and land management program will be conducted...that promotes the conservation and enhancement of" forests and woodlands, fish and wildlife populations and habitat, threatened and endangered species, prime and unique farmland, soils and vegetation, native prairies and grasslands, surface water and groundwater supplies and quality, wetlands and flood plains, cultural and historical resources, outdoor recreation resources, esthetics, public access opportunities, and nonconsumptive uses (e.g., birdwatching, photography, and hiking). Clearly, such a comprehensive program would play a significant role in controlling NPS pollution.

While not specifically directed toward NPS pollution control, several related Army environmental initiatives are currently underway. These include waste minimization and management, land management, pesticide management, spill prevention and control, source reduction, and recycling and reclamation. Successful implementation of these programs can be expected to provide concurrent benefits by mitigating and reducing NPS pollution.

## **Regulations**

Regulatory efforts in the area of NPS are recent and are undergoing continuing development, as well as controversy. One apparent trend, however, is an attempt by USEPA to be more flexible and rely more heavily on voluntary and market-driven approaches. Not only is USEPA already burdened with massive regulatory programs, but the highly varied nature of NPS pollution prevents it from being controlled by traditional command-and-control strategies. Rather than numerical limits, new NPS rules are likely to use a series of management practices to be instituted as appropriate (Table 1).

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<sup>4</sup> AR 200-1, Chapter 3.2, parts f and g.



Table 1

## Traditional Versus Modern Stormwater Management Approaches

Traditional Approach	Modern Approach
Remedial, emphasis on problem correction	Preventive, emphasis on problem avoidance
Stormwater considered "enemy"	Stormwater considered useful
Single purpose	Multiple purpose
Site-oriented	Watershed-oriented, downstream impacts considered
Conveyance-oriented, rapid removal from land	Storage-oriented, controlled release from facilities
Engineers and technicians determine plans and measures	Local officials provide direction and decisions on policy options
Piecemeal projects	Systems approach, plans and projects linked

USEPA has been directed to incorporate stormwater NPS controls into the NPDES program. At first, USEPA attempted to do so using rather general permits that would include many nonpoint sources together. Categorical use of this approach was struck down, however, and now a combination of individual, group, and general permits will be used.

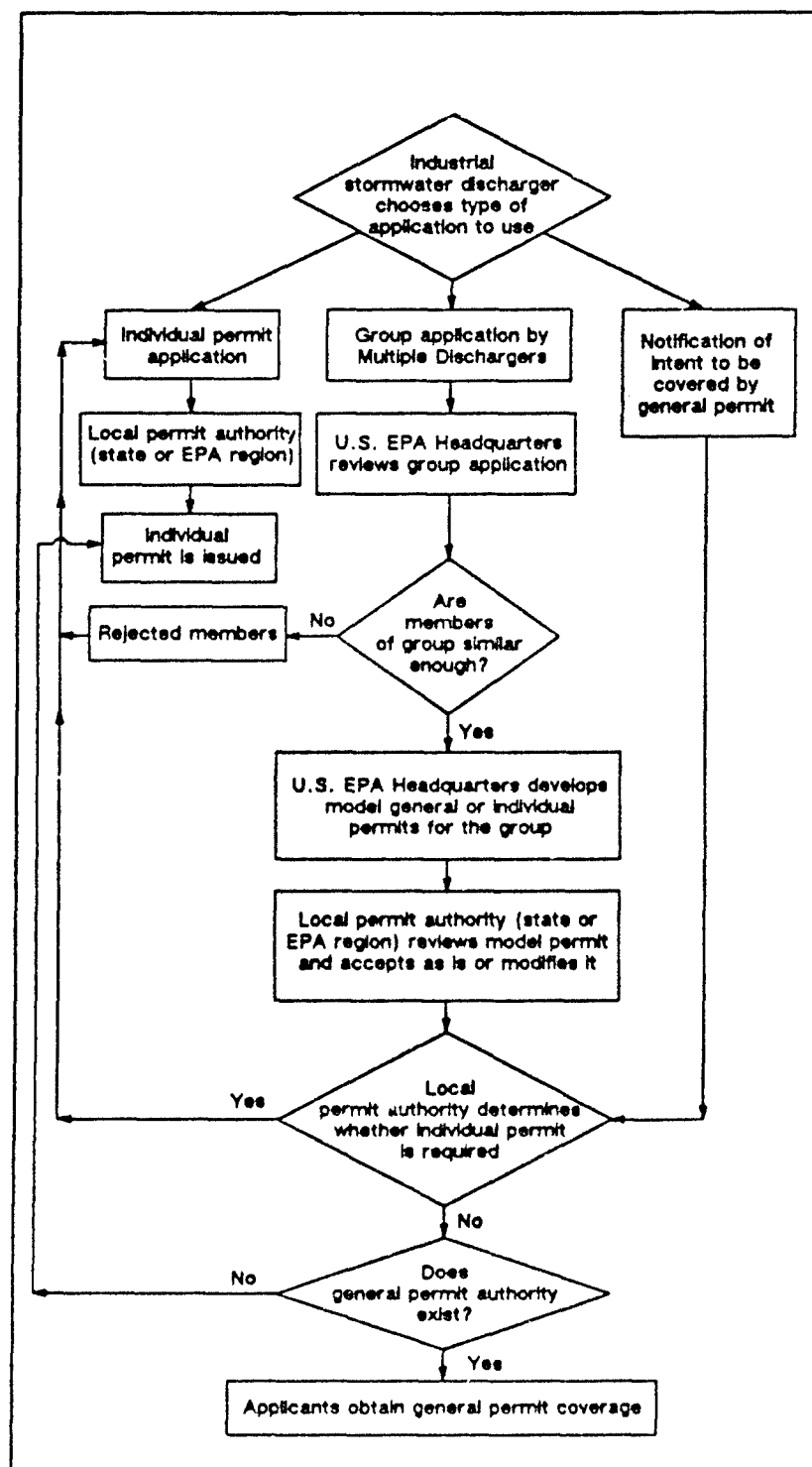
The primary rules for the control of NPS through the NPDES program are contained in 40 CFR, Parts 122 through 124. Current efforts focus on the required stormwater discharge permits associated with industrial activities and municipalities (those with separate storm sewer systems serving populations in excess of 100,000) (40 CFR 122.26). Final rules providing detailed requirements for individual and group industrial permit and municipal permit applications were published in the Federal Register (FR) on 16 November 1990 (55 FR 47990).

The term "industrial" was broadly defined to include any conveyance that collects and conveys stormwater and is directly related to manufacturing, processing, or raw material storage areas at an industrial plant. Included are certain Wastewater Treatment Plant (WWTPs) flows greater than 1 million gallons per day [mgd]<sup>\*</sup>, transportation facilities, landfills, construction sites, and some recycling centers. A request for comments on the industrial rules was published in the Federal Register on 16 August 1991 (56 FR 40948). (Excluded was stormwater runoff from certain mining and oil and gas activities, not of importance to the Army [40 CFR 122.26].)

The permit process is diagrammed in Figure 1. The requirements for individual applications are found in 40 CFR 122.26(c)(1). Group applications, for facilities with similar stormwater characteristics, are to be filed in two parts. Part 1 identifies the facilities covered by the application and provides other general information. USEPA has the right to reject any or all members of the group. Part 2 contains detailed information, including sampling data, for approximately 10 percent of the facilities in the group [40 CFR 122.26(c)(2)]. A third class of permit is the general (generic) permit (see 56 FR 40948, 16 August 1991), the use of which requires filing a Notice of Intent (NOI); acceptance is granted by the USEPA on a case-by-case basis. General permits can be used in place of group or individual permits if the permittee agrees to a number of conditions; however, the Army has elected not to pursue the use of general permits.

The deadline for filing permit applications for individual industrial dischargers (including those rejected from group applications) was extended to 1 October 1992 (56 FR 56548, 5 November 1991). Industrial dischargers were also to notify the WWTP to which they discharge stormwater by 31 May 1991.

<sup>\*</sup>A metric conversion table is on page 95.



(Source: *Water Environment and Technology* [Water Environment Federation, March 1991], p 53. Used with permission.)

Figure 1. Obtaining an Industrial Storm Permit.

Through this process, the municipality may impose pollutant control provisions on stormwater discharges and incorporate them into the permit.

New regulations will require Army installations to apply for and obtain NPDES stormwater permits. The Army has decided to categorize all its facilities as industrial for purposes of these rules. The Army has filed two group permit applications; the first covers all Army reserve centers, and the second covers active Army installations including Fort Monmouth, but exclusive of other Army Materiel Command (AMC) locations. Remaining AMC installations will apply for individual permits. For the reserve centers and troop-type installations, abatement strategies will include efforts to control solids, oil and grease, and fuels from vehicles and aircraft. For the industrial-type installations, efforts will focus on controlling contaminated runoff.

The complex regulations are continuously evolving. Installation environmental managers must also verify and comply with current state regulations and requirements.

The standard to be followed is reduction of pollution to the maximum extent practicable (MEP) achieved by a combination of best management practices (BMPs), control techniques, and design features. Industrial dischargers must institute best available technology (BAT) and best conventional pollutant control technology (BCT). BCT focuses on "conventional" pollutants such as biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), pH, and fecal coliform bacteria, whereas BAT is directed more toward toxic metals and organic pollutants.

The other major current initiative is the development by the states of comprehensive coastal nonpoint source control programs, through authority of CZARA. These programs will apply only in designated coastal areas (all or portions of 29 states). The USEPA has prepared technical guidance documents to assist in the development of these plans; the comment period ended in December 1991. The programs are to control NPS pollution from sources including "agriculture, silviculture, urban (including construction activities), hydromodification, and marinas" (56 FR 27168, 14 June 1991). The programs are scheduled to be submitted to USEPA in 1994 (the state can choose to implement them earlier), and will likely impose additional requirements on Army installations in affected areas.

A general process for developing state Water Quality Management Plans (WQMPs) is outlined in 40 CFR Part 130, which incorporates NPS control considerations. These plans "shall describe the regulatory and non-regulatory programs, activities and ...BMPs which the State agency has selected as the means to control nonpoint source pollution where necessary to protect or achieve approved water uses" (40 CFR 130.6(c)(4)). A new related rule requires the states to submit a list of water quality-limited waters to the USEPA every 2 years and to integrate needed nonpoint source control measures into the WQMP. 40 CFR Part 125 (Subpart K) discusses the criteria and standards for BMPs for controlling toxic and hazardous pollutants from industrial sources. These BMPs can be incorporated into the applicable (point source) permit, and may be integrated with the facility's spill control program under CWA Section 311.

Among the goals of the FSA and the FACTA is the conversion of highly erodible or other sensitive cropland to less intensive uses. The Acts establish in 7 CFR Parts 704 and 1410 the Environmental Conservation Acreage Reserve Program (ECARP, which includes the Conservation Reserve Program) administered by the Commodity Credit Corporation (CCC) of the U.S. Department of Agriculture (USDA). If the owner of eligible cropland will implement an acceptable conservation plan and establish a vegetative or acceptable water cover for 10 to 15 years, CCC will share the costs of conversion, provide technical assistance, and provide annual compensatory rental payments. Final rules were published in 56 FR 15980, 19 April 1991. [Note: As a Federal entity, the Army is not eligible to receive assistance under ECARP. A farmer leasing Army land may be eligible, but only if he had full control of the land for the full period

of the agreement (10 to 15 years).] USEPA assists in this program by identifying areas where nonpoint source pollution is a significant contributor to water quality problems. The ECARF's target is 40 to 45 million acres by 1995, of which 34 million acres were already enrolled by 1990.

USEPA also issued a national strategy for the control of combined sewer overflows (CSOs) on 10 August 1989. The states must inventory all CSO points and issue permits to control them. Little funding was provided to implement the strategy, however, and there has been limited progress to date. One issue is whether controls will be technology-based or water-quality based. While control of CSOs is primarily of concern for older large cities, it may be applicable at some Army installations.

Under CZARA, the states must develop comprehensive coastal NPS control programs (with Federal assistance and guidance) and implement them. These programs are scheduled to be completed during the mid-1990s, and can be expected to impose additional requirements on Army installations in coastal areas. USEPA issued guidance requesting public comment on management measures to control nonpoint source pollution from sources including "agriculture, silviculture, urban (including construction activities), hydromodification (e.g., dams, levees, shoreline erosion control measures), and marinas" (56 FR 27618, 14 June 1991). These comments and guidelines will be used to develop effective state programs.

It also should be noted that recent court cases have held that upstream NPS polluters can be held responsible for the costs of correcting pollution impacts suffered downstream.<sup>5</sup> The situation is dynamic; some regulations may yet change.

### Opportunities for Nonpoint Source Control Initiatives

The level of control that exists on Army installations provides opportunities not possible in civilian settings. Education of all installation personnel regarding how their activities—at work, in their quarters, or at play—can unwittingly contribute to nonpoint source pollution is warranted. Improper use of storm sewers or dumping of used oil, old paint, pesticides, cleaning fluids, antifreeze, etc., constitute sources of nonpoint source pollution.

Improved housekeeping in work areas, storage areas, and throughout the installation, as well as improved operating practices, can have a surprisingly beneficial effect. At an organizational level, the solid waste collection and disposal practices of an installation affect nonpoint source pollution, as do litter control, grounds maintenance, training area activities, construction activities, and land use planning.

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<sup>5</sup> R.F. Scheuerman, "Stormwater Management Should Have a Watershed Approach," *Water Environment and Technology*, vol 3 (September 1991), pp 238-239.

### 3 ARMY INSTALLATION CHARACTERIZATION

The Department of Defense and the Army are required to follow Federal and state laws and regulations on environmental management. Individual installations also strive to maintain a "good neighbor" image by participating in activities of local watershed management boards, and other environmental organizations.

Training areas within the Army have received extensive attention at addressing NPS pollution from erosion due to maneuver activities. Ongoing research programs and maintenance and rehabilitation programs ensure that the Army is able to train without deteriorating valuable natural resources. Environmental managers on post also are responsible for agricultural and silvicultural activities at their installations. Naval researchers have found lead and other heavy metal contamination at firing ranges; the same situation may exist at Army ranges.

Cantonment areas are similar to well-maintained small cities with all the accompanying activities. For example, fertilizer and pesticides are applied to lawns in residential areas. This is a potential source of pollution due to the tendency of residents to overapply lawn chemicals. One helpful practice is to have installation staff apply these chemicals. This practice will help limit chemicals to the amount most appropriate for the situation. This kind of control is unique to the military.

Motor pools are a potential source of nonpoint source pollution for a variety of contaminants: petroleum, oils, and lubricants (POLs); fuels; heavy metals; asbestos; and solvents that may runoff the hardstand or paved areas. Many installations have oil/water separators to mitigate the pollution. However, success of the separators varies depending on operation and maintenance.

Most installations have not conducted comprehensive surveys of contaminants from nonpoint sources, although that situation is currently changing as they respond to the permitting requirements of the stormwater rule. Most installations are being required to seek NPDES permits for their stormwater discharges as industrial facilities. Installations are being grouped under the various major commands and representative installations are having extensive surveys conducted during runoff events to comply with the application process. Geographical and climatological groups have been formed. AMC installations are responding to the rule requirements individually due to their unique functions.

Researchers at the U.S. Army Construction Engineering Research Laboratories (USACERL) reviewed sediment/erosion control on Army training lands.<sup>6</sup> They presented a summary survey of current technology classifying and discussing methods, materials, and structures. Erosion control measures are classified according to their roles in disrupting erosion: soil stabilization, runoff management, and sediment control. Engineering technologies for erosion control are identified in the areas of landforming, materials, and structures in a brief and general format. The authors present information on soil stabilization categorized under landforming measures, materials including mulches, geosynthetic materials, chemical stabilizers and soil binders, and concrete block material, and structures and systems for soil stabilization including erosion checks, revetments, retaining structures, and subsurface drainage systems. Their review of runoff management includes landforming measures: terraces, benches, grassed waterways, level spreader, diversions, and filling and reshaping. Further techniques include materials for runoff management including manufactured linings, and more permanent materials such as riprap, gabions, concrete, flexible mats, etc. Structures and systems include various grade stabilization structures and

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<sup>6</sup> E.G. Vachta and R.E. Riggins, *Erosion Control Methods for Army Training Land Rehabilitation: Survey of Current Technology*, USACERL Technical Report N-88/05/ADA197566 (U.S. Army Construction Engineering Research Laboratories [USACERL], May 1988).

energy dissipation structures. They also introduce sediment control measures including landforming, materials to trap or prevent the movement of sediment and slow runoff, (e.g., filter fabrics, straw bales, sand bags, and gravel) and structural alternatives including barriers, basins, and traps.

Further research in the area of erosion control in training lands has seen the development of an erosion control management plan for individual installations.<sup>7</sup> This is part of the Integrated Training Area Management (ITAM) approach adopted by the Army. Procedures are presented to accurately identify erosion problems, assess needs, select appropriate solutions, and compare costs of alternatives.

The U.S. Army Center for Public Works (USACPW) is issuing a Public Works Technical Bulletin (PWTB) titled Assessment of Nonpoint Source (NPS) Pollution Potential at Military Bases. That PWTB provides guidance on how to assess nonpoint source pollution at Army installations by defining terms and giving background information, and specifying how to (1) determine the volume of runoff, (2) sample water and analyze water quality, (3) evaluate data, and (4) assess nonpoint source pollution effects. The TN also provides a sample application of these procedures to a hypothetical Army installation.

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<sup>7</sup> E.G. Vachta and R.E. Riggins. *Erosion Control Management Plan for Army Training Lands*, USACERL Technical Report N-90/11/ADA226558 (USACERL, June 1990).

#### 4 SELECTION OF BMPS

Planners and engineers need to consider several factors when choosing best management practices. First, the objectives of the BMP should be decided. Screening tools may be useful to select the most appropriate options for a particular site. Screening tools to evaluate the following were described for urban runoff BMPS.<sup>8</sup>

- BMP options that are suitable for a site, given its physical condition and development status.
- Stormwater control benefits provided by each option.
- Expected pollutant removal capability for each BMP option, under different design scenarios.
- Environmental and human amenity values associated with the BMP option selected.

Experience with BMPS has shown that each has unique capabilities and limitations. These must be balanced with the physical constraints of the site and overall management objectives of the watershed. During the review process, the ultimate objectives for managing the runoff flow must be identified. The following goals have been suggested:<sup>9</sup>

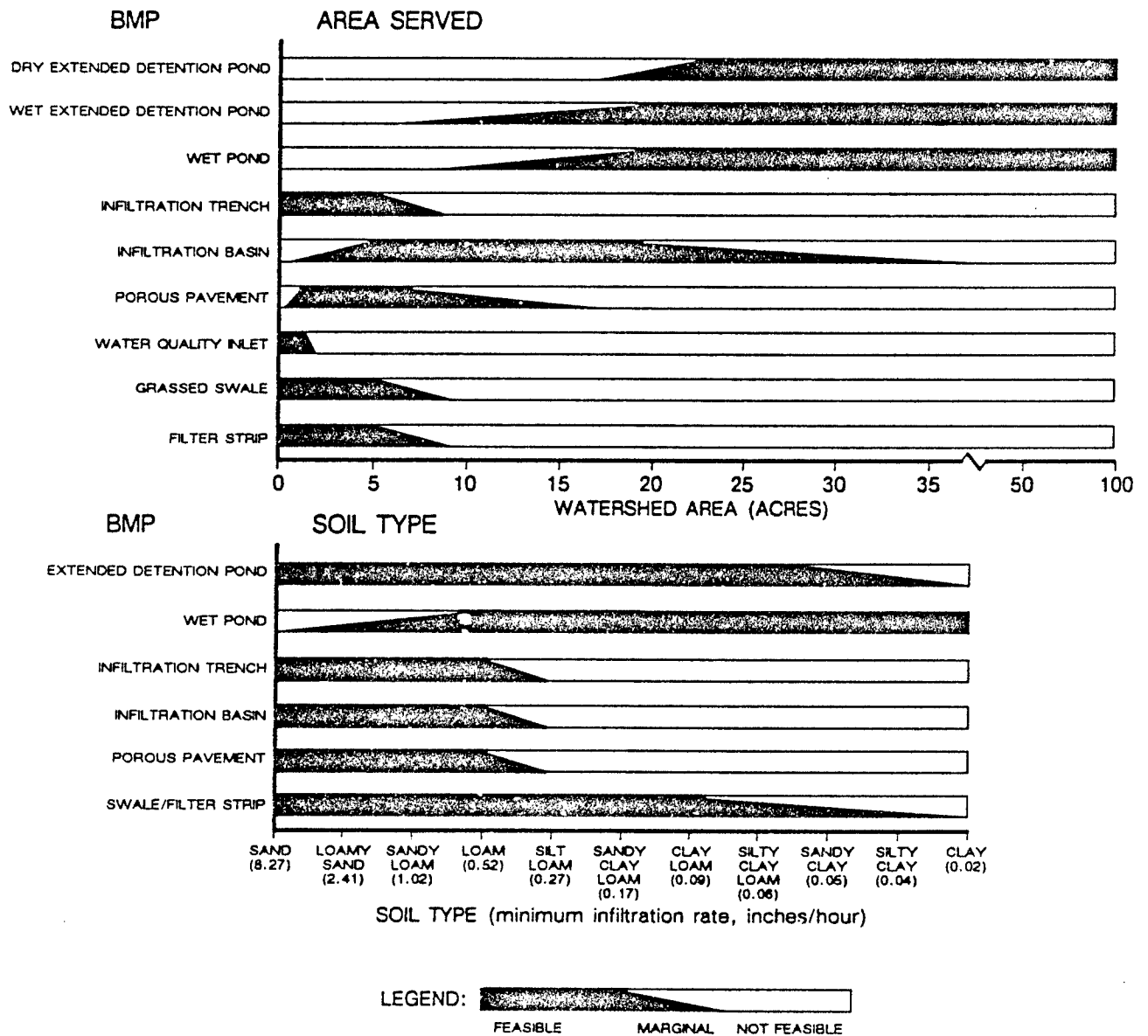
- Reproduce, as nearly as possible, the hydrological conditions in the stream before development.
- Provide a moderate level of removal for most urban pollutants.
- Use a BMP that is appropriate for the site, given physical constraints.
- Ensure the BMP is reasonably cost-effective in comparison with other BMPS.
- Consider the acceptable future maintenance burden.
- Minimize (or neutralize) the impact on the natural and human environment.

Researchers have presented screening tools to aid planners or engineers in choosing the BMP for sites. Information in Figures 2 and 3 is used to identify options physically feasible for the site. Figure 4 summarizes the stormwater benefits provided by each BMP option. Figure 5 provides rapid guidance on the relative pollutant removal capability of BMPS for a number of urban pollutants. Figure 6 indicates what natural or human amenities, if any, can be provided by the BMP. Further information on many of these BMPS is in other chapters of this report.

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<sup>8</sup> T.R. Schueler, *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPS* (Metropolitan Washington Council of Governments, Washington DC, 1987).

<sup>9</sup> T.R. Schueler.



(Source: Schueler, 1987. Used with permission.)

**Figure 2. Watershed Area and Soil Permeability Restrictions for BMPs.**



BMP	SLOPE	HIGH WATER TABLE	CLOSE TO BEDROCK	PROXIMITY TO FOUNDATIONS	SPACE CONSUMPTION	MAXIMUM DEPTH	RESTRICTED LAND USES	HIGH SEDIMENT INPUT	THERMAL IMPACTS
EXTENDED DETENTION POND	●	●	◐	●	○	●	●	◐	●
WET POND	●	●	◐	●	○	○	●	◐	○
INFILTRATION TRENCH	○	○	○	○	●	○	●	○	●
INFILTRATION BASIN	◐	○	○	◐	◐	○	●	○	●
POROUS PAVEMENT	○	○	○	○	○	○	○	○	●
WATER QUALITY INLET	●	●	○	○	●	○	○	○	●
GRASSED SWALE	○	○	◐	◐	●	●	○	○	●
FILTER STRIP	◐	◐	◐	◐	●	●	◐	○	●

- MAY PRECLUDE THE USE OF A BMP
- ◐ CAN BE OVERCOME w/CAREFUL SITE DESIGN
- GENERALLY NOT A RESTRICTION

(Source: Schueler, 1987. Used with permission.)

Figure 3. Other Common Restrictions on BMPs.

BMP	PEAK DISCHARGE CONTROL					
	2 YEAR STORM	10 YEAR STORM	100 YEAR STORM	VOLUME CONTROL	GROUNDWATER RECHARGE	STREAMBANK EROSION CONTROL
EXTENDED DETENTION						
DRY	●	●	●	○	○	●
DRY w/MARSH	●	●	●	◐	○	●
WET	●	●	●	○	○	●
WET POND	●	●	●	◐	○	○
INFILTRATION TRENCH						
FULL EXFILTRATION	●	◐	○	●	●	●
PARTIAL EXFILTRATION	●	●	○	●	●	●
WATER QUALITY TRENCH	○	○	○	●	●	●
INFILTRATION BASIN						
FULL EXFILTRATION	●	◐	○	●	●	●
INFILTRATION/DETENTION	●	●	●	●	●	◐
OFF-LINE BASIN	○	○	○	●	●	◐
POROUS PAVEMENT						
FULL EXFILTRATION	●	◐	○	●	●	●
PARTIAL EXFILTRATION	●	●	◐	●	●	◐
WATER QUALITY	○	○	○	●	●	◐
WATER QUALITY INLET	○	○	○	○	○	○
GRASSED SWALE	◐	○	○	◐	◐	○
FILTER STRIP	◐	○	○	◐	◐	○

○ SELDOM OR NEVER PROVIDED

◐ SOMETIMES PROVIDED w/CAREFUL DESIGN

● USUALLY PROVIDED

(Source: Schueler, 1987. Used with permission.)

Figure 4. Comparative Stormwater Benefits Provided by Urban BMPs.

BMP/design	SUSPENDED SEDIMENT	TOTAL PHOSPHORUS	TOTAL NITROGEN	OXYGEN DEMAND	TRACE METALS	BACTERIA	OVERALL REMOVAL CAPABILITY
<b>EXTENDED DETENTION POND</b>							
DESIGN 1	●	○	○	○	○	⊗	MODERATE
DESIGN 2	●	○	○	○	○	⊗	MODERATE
DESIGN 3	●	●	○	○	○	⊗	HIGH
<b>WET POND</b>							
DESIGN 4	●	○	○	○	○	⊗	MODERATE
DESIGN 5	●	○	○	○	○	⊗	MODERATE
DESIGN 6	●	●	○	○	○	⊗	HIGH
<b>INFILTRATION TRENCH</b>							
DESIGN 7	●	○	○	○	○	●	MODERATE
DESIGN 8	●	○	○	○	○	●	HIGH
DESIGN 9	●	●	○	○	○	●	HIGH
<b>INFILTRATION BASIN</b>							
DESIGN 7	●	○	○	○	○	●	MODERATE
DESIGN 8	●	○	○	○	○	●	HIGH
DESIGN 9	●	●	○	○	○	●	HIGH
<b>POROUS PAVEMENT</b>							
DESIGN 7	○	○	○	○	○	●	MODERATE
DESIGN 8	●	○	○	○	○	●	HIGH
DESIGN 9	●	●	○	○	○	●	HIGH
<b>WATER QUALITY INLET</b>							
DESIGN 10	○	⊗	⊗	⊗	⊗	⊗	LOW
<b>FILTER STRIP</b>							
DESIGN 11	○	○	○	○	○	⊗	LOW
DESIGN 12	●	○	○	○	○	⊗	MODERATE
<b>GRASSED SWALE</b>							
DESIGN 13	○	○	○	○	○	⊗	LOW
DESIGN 14	○	○	○	○	○	⊗	LOW

KEY:

- 0 TO 20% REMOVAL
- ◐ 20 TO 40% REMOVAL
- ◑ 40 TO 60% REMOVAL
- ◒ 60 TO 80% REMOVAL
- 80 TO 100% REMOVAL
- ⊗ INSUFFICIENT KNOWLEDGE

- Design 1: First-flush runoff volume detailed for 8-12 hours.  
 Design 2: Runoff volume produced by 1.0 inch, detained 24 hours.  
 Design 3: As in Design 2, but with shallow marsh in bottom stage.  
 Design 4: Permanent pool equal to 0.5 inch storage per impervious acre.  
 Design 5: Permanent pool equal to 2.5 (Vr); where Vr = mean storm runoff.  
 Design 6: Permanent pool equal to 4.0 (Vr); approx. 2 weeks retention.  
 Design 7: Facility exfiltrates first-flush; 0.5 inch runoff/imper. acre.  
 Design 8: Facility exfiltrates one inch runoff volume per imper. acre.  
 Design 9: Facility exfiltrates all runoff, up to the 2 year design storm.  
 Design 10: 400 cubic feet wet storage per impervious acre  
 Design 11: 20 foot wide turf strip.  
 Design 12: 100 foot wide forested strip, with level spreader  
 Design 13: High slope swales, with no check dams.  
 Design 14: Low gradient swales with check dams.
- (Source: Schueler, 1987. Used with permission.)

Figure 5. Comparative Pollutant Removal by Urban BMP Designs.

BMP	LOW FLOW MAINTENANCE	STREAMBANK EROSION CONTROL	AQUATIC HABIT CREATION	WILDLIFE HABITAT CREATION	NO THERMAL ENHANCEMENT	LANDSCAPE ENHANCEMENT	RECREATIONAL BENEFITS	HAZARD REDUCTION	AESTHETICS	COMMUNITY ACCEPTANCE
DRY EXTENDED DETENTION	○	●	◐	●	●	◐	◐	◐	◐	◐
EXTENDED DETENTION w/MARSH	○	●	◐	●	○	◐	◐	◐	◐	◐
WET EXTENDED DETENTION	○	●	●	●	○	●	●	◐	◐	●
WET POND	○	○	●	●	○	●	●	◐	◐	●
INFILTRATION TRENCH	●	◐	○	○	●	○	○	●	○	●
INFILTRATION BASIN	●	◐	○	●	●	◐	◐	●	○	◐
POROUS PAVEMENT	●	◐	○	○	●	○	○	●	○	●
WATER QUALITY INLET	○	○	○	○	●	○	○	●	○	●
GRASSED SWALE	◐	○	○	◐	●	◐	○	●	◐	●
FILTER STRIP	◐	○	○	●	●	◐	○	●	◐	●
SHALLOW MARSH	○	○	●	●	○	◐	○	◐	◐	◐

○ SELDOM PROVIDED  
 ◐ SOMETIMES PROVIDED (w/Design Modifications)  
 ● USUALLY PROVIDED

(Source: Schueler, 1987. Used with permission.)

Figure 6. Environmental and Community Amenities Provided by BMPs.

## **5 BEST MANAGEMENT PRACTICES (BMPS)**

Best Management Practices, as a general term, designate any method for controlling the quantity and quality of stormwater runoff. Typically, a BMP is considered to be either (1) a practice (routine procedure) that reduces the pollutants available for transport by the normal rainfall-runoff process, or (2) a device that reduces the amount of pollutants in the runoff before it is discharged to a surface waterbody. The following discussion examines BMPs primarily in the urban runoff category and evaluates some measures applicable to construction, silviculture, erosion control, and agriculture. Areas not addressed include hydromodification (locks and dams) and marinas and recreational boating.

The following presentation format is to review urban BMPs, detail a number of the structural options, and briefly summarize options for construction, forestry, and agriculture. There are, of course, overlaps between various measures and a cursory knowledge of available options may aid in making an appropriate choice.

Urban BMPs are a set of controls designed to reduce pollutants in urban runoff: sediment, nutrients, heavy metals, bacteria, pesticides/fertilizers, oxygen-demanding substances that deplete dissolved oxygen (DO) levels in receiving waters (COD, BOD) oil and grease, and others.

The following urban BMPs are listed individually, but in practice, BMPs can and should be considered in combination for greater pollutant reduction. For example, consider incorporating vegetated filter strips and detention basins to reduce sediment loads to a wetland, or use filter strips for pretreatment of inflows to infiltration systems. Specific site characteristics such as soil permeability and drainage area will determine the BMP types and combinations most appropriate for each case. The following is not an exhaustive list of the possible control practices; designers are not limited to the BMPs discussed in this section.

### **Pollution Source Controls**

1. Fertilizer application control.
2. Pesticide application control.
3. Vegetative controls - revegetation immediately after soil disturbance.
4. Retain natural vegetation - as much existing vegetation as possible should be retained on a given site.
5. Buffer strips - vegetation should be created or retained along the banks or edges of all waterbodies and wetlands.
6. Vegetated filter strips, waterways, and seepage areas - (biofiltration) use grassed surfaces to reduce runoff velocities, enhance infiltration, and remove runoff contaminants. Periodic maintenance is required to remove the accumulated materials so contaminants are not released in a later storm.
7. Construction site management - use good management and "housekeeping" techniques on sites to reduce the availability of construction-related pollutants where runoff contamination cannot be avoided, to retain the pollutants and polluted water on site. Concepts include erosion and sediment protection, trash collection and disposal, the use of designated washing areas for cleaning equipment, proper material storage dust control at demolition sites, use of proper sanitary equipment and pesticide use control.

## **Solid Waste Collection and Disposal**

8. Storage containers - receptacles for the temporary storage of refuse should be designed specifically for the type of waste to be stored. They should be covered and have leakproof bottoms. Containers for mixed refuse should not exceed 30 to 32 gallons in capacity and should be equipped with handles to facilitate handling.

9. Refuse collection - loading of refuse into the collection vehicle and traveling along the collection route may cause a great amount of refuse to become scattered and blown about thereby becoming litter (uncontained waste). Refuse crews should be instructed to use caution when emptying trash cans or otherwise loading their vehicles to limit amounts of the material blown either from the cans or out of the vehicle hopper during the loading activities. Local authority can minimize the blowing of litter from collection vehicles by requiring that the vehicle's compaction mechanism be used at each collection stop. However, this compaction policy notably reduces collection efficiency and thus increases costs.

10. Litter control - litter, or "uncontained solid waste," is the visible trash found along roadsides, vacant lots, sidewalks, and parks. Vacant lots should be made secure in every way feasible against illegal dumping. Enforcement of ordinances against illegal dumping and littering by pedestrians and motorists is difficult, but necessary. Police and health and sanitation workers should be delegated authority to enforce local ordinances.

11. Leaf disposal - leaves should be collected and stored, unshredded (shredding tends to release the phosphorous from the leaves much faster), away from drainageways until they are collected. Leaves should not be burned; this practice presents a hazard to persons with respiratory ills and is a nuisance to others. The ash is a significant source of phosphorous. Leaves can be shredded for mulch, plowed into a garden, or composted to provide important ingredients of good soil for lawns and gardens.

## **Runoff Collection - Distribution**

12. Sheet flow - usually requires only grading and seeding during construction.

13. Grass swales - grassed low areas graded at a minimum of 4:1 side slopes. Swales are shallow grass-covered channels, rather than buried storm drains, used to convey stormwater. Grass channels are mostly applicable in residential areas. They require shallow slopes, and soils that drain well. Often grass swales are used to provide "pretreatment" of runoff to other controls, particularly infiltration devices.

14. Filter strips - similar in concept to grass swales, filter strips are designed to distribute runoff across the entire width of an area, resulting in an overland sheet flow. These strips should have relatively low slopes, adequate length, and should be planted with erosion-resistant species. Filter strips are often used as pretreatment, for example, by being placed in the flow path between a parking lot and an infiltration trench.

15. Oil and grease filtering catch basins, and oil and grease separators - structures designed to collect and distribute runoff coming from parking areas and other areas with high vehicle use. They rely on the principle that oil floats on water, and most remove petroleum products through a specially designed "T" outlet. Separators are maintenance-intensive devices: oil and grease must be removed periodically or these substances will become resuspended or re-emulsified and sidecharged through the "T" outlet during subsequent storms. Traps can also be flooded during particularly intense storms, allowing separated oil to flow freely. Coalescing plate oil separators work well under certain conditions, but they are expensive to install and maintain. Still they represent a promising technology for specific areas where petroleum products are routinely released to the ground surface.

16. Raised catch basins - catch basins constructed so that the top lip of the catch basins is raised 1 or 2 in. above the surrounding swale or surface elevation.

17. Dual compartment catch basins - similar to other catch basin designs except that these contain multiple compartments.

18. Dry wells/seepage pits - cavities dug into the ground and filled with gravel or rocks. These work on the principle of returning stormwater directly to the groundwater. One nationwide study found these infiltration devices to be effective when accompanied by sound design and maintenance, although they have the potential for contaminating groundwater if the stormwater they collect and conduct is contaminated. Since clogging is a problem, infiltration devices can only be used in areas where the soil is very permeable.

19. Detention ponds - ("dry ponds") a water impoundment made by constructing a dam or embankment or by excavating a pit to detain stormwater and discharge a controlled volume. Detention basins hold back a portion of the runoff, delaying release to receiving waters and preventing flooding. The settling out of contaminants from runoff that occurs during detention improves water quality. The effectiveness of detention ponds is reduced, however, when maintenance is neglected. Common problems include blocked outlets, accelerated sedimentation, and standing water in "dry" areas. The Metropolitan Washington D.C. Council of Governments has estimated the cost of detention basin maintenance at approximately \$300 to 500 per maintained acre per year.

20. Extended detention ponds - these basins use an outlet structure that will cause most storms to pond in the basin. Following a storm, these basins drain in about 24 to 40 hours and will be dry at all other times. The outlet structures may be either perforated risers or subsurface drains. They provide a practical technique for retrofitting dry ponds to obtain water quality benefits, and can provide particulate removal efficiency equivalent to that for wet ponds.

21. Retention pond - ("wet ponds") a water impoundment made by constructing a dam or embankment or by excavating a pit to retain stormwater and discharge a controlled volume. These are similar to detention basins but are designed to retain a portion of the runoff, "saving" this water for later recharge of streams or allowing it to evaporate during dry seasons. As ponded runoff infiltrates the ground, pollutants may be filtered out or adsorbed onto soil particles. Routine maintenance costs are also similar to those of detention basins, although USEPA has found that the cost of constructing these controls may be as much as 40 percent higher than the cost of detention basins. Removal efficiency depends on the size of the basin and the area draining into it. Efficiency may be enhanced by the use of a device upstream of the basin that intercepts the first flush of sediment and other pollutants during a storm.

22. Basin landscaping - Basin landscaping can be addressed during early development of a watershed and can have a significant effect on the control of NPS pollutants. The objectives of basin landscaping include but are not limited to minimization of impervious surface area; protection and use of existing wetlands; provision for green-belt buffers along stream banks; and routing of runoff flow through vegetated areas and away from erosion-prone steep slopes. Careful selection of vegetation most suitable for site conditions has an important bearing on physical appearance and the long-term performance of basin landscaping.

23. Parking lot storage - use impervious parking areas as temporary impoundments during rainstorms. Parking lot drainage systems can be designed to temporarily detain stormwater in special designated areas, and release it at a controlled rate. The objective is to protect downstream areas from increased flooding, stream channel degradation, and/or combined sewer overflows caused by urban development. It is important to minimize potential safety hazards and inconvenience to motorists and pedestrians.

24. Parking lot planting areas - areas within a parking lot set aside for plants and shrubbery.

25. Discharge structures - final elevation of a stormwater discharge outlet is at or above the edge of critical areas.

26. Dikes and berms or level spreaders - vegetated linear ridges of earth used to control runoff.

27. Culvert riser - upward-extending perforated pipe fitted over the intake area of a culvert.

28. Rooftop storage - roof areas used to store water for a detention or retention device. Rooftop detention can be incorporated into the design of most new buildings, and many existing buildings can be modified for this function.

29. Cistern storage - collection and storage of stormwater runoff in a storage tank or chamber above or below the ground. A cistern can serve as a detention device to protect downstream areas from flooding, stream channel degradation, and/or sewer overflows, or it can be used to collect polluted runoff for later treatment. Collected water may also be used to water lawns, for fire protection, or other purposes.

30. Building setback - buildings and other structures associated with development projects should be set back from marshes or other waterfront locations.

31. Conventional flow regulators - mechanical devices in stormwater conveyance and storage facilities to provide control of the volumes, velocities, and directions of fluid flows in order to maximize the operating efficiencies of these systems (static regulators, semiautomatic dynamic regulators, and automatic dynamic regulators).

32. Fluid flow regulators - innovative self-powered and controlled fluid flow regulators provide numerous advantages over conventional flow regulators, among them lower installation cost, a greater range of flow control, and less maintenance. Depending on the design and application, these devices can be used to selectively divert the first flush of a storm into treatment facilities or temporary storage areas, to automatically proportion runoff flows between receiving streams and retention or detention facilities; or to provide increased operating efficiency of storm and combined sewers during wet weather flows. All of these functions serve to reduce the impacts on receiving waters.

#### **Runoff and Erosion/Sediment Controls**

33. Topsoiling before establishment of vegetation.

34. Vegetative stabilization with

- a. temporary seeding,
- b. permanent seeding,
- c. mulching,
- d. sod, trees, shrubs, vines, and ground cover.

35. Dikes and berms or level spreaders - vegetated linear ridges of earth used to control runoff.

36. Silt fences, hay bales, or other approved erosion control measures properly installed around storm sewer inlets and boundaries of disturbed areas.

37. Temporary check dams - used to slow stream flow and allow sediment to be deposited.

38. Sandbagging.

39. Straw bale dike.



40. Earth dike.
41. Perimeter dike swale.
42. Sump pit (May have an adverse effect on groundwater).
43. Diversion.
44. Temporary storm drain diversion.
45. Subsurface drain (May have an adverse effect on groundwater).
46. Stabilization construction entrance - stabilized pad of aggregate on a filter cloth base located at any point where traffic will be entering a construction site to or from public right-of-way, street, alley, sidewalk, or parking area to prevent site access points from becoming sediment sources.
47. Pipe drop structure.
48. Discharge structures - final elevation of a stormwater discharge outlet is at or above the edge of critical areas.
49. Sediment basins.
50. Portable sediment tank.
51. Storm inlet sediment trap.
52. Swale sediment trap.
53. Stone outlet sediment trap.
54. Riprap outlet sediment trap.
55. Optional dewatering device for sediment traps.
56. Temporary access waterway crossings
  - temporary access bridge
  - temporary access culvert
  - temporary ford: shallow structure placed in the bottom of a waterway over which water flows while still allowing traffic to cross the waterway.
57. Riprap - use in exposed areas especially susceptible to erosion.
58. Rock-lined ditches - a conventionally constructed ditch with a layer of loose gravel type rock material lining the bottom.
59. Stabilization of channels and steep slopes using erosion control matting.
60. Protection of trees in urbanizing areas.

61. Curbs - can convert streets and parking areas into open stormwater channel and storage facilities. Interrupted, pierced, or perforated curbing will allow sheet flow of runoff.

62. Rooftop discharge locations - a system for collecting, controlling, and disposing of runoff water from rooftops.

### **Paving Material**

Minimize impervious surfaces - many surfaces can be made pervious or modified to reduce the impact of flooding during rainy weather. Reduction in the amount of impervious surfaces lowers the amount of surface water runoff, and therefore, can achieve a reduction in pollution.

63. Pervious asphalt paving - pervious asphalt allows water to pass through the surface and is infiltrated into the subsurface soils. This may be expensive and may require some maintenance to prevent clogging and loss of effectiveness.

64. Paving blocks - used to support automobile traffic and still leave enough unpaved area to allow water infiltration.

65. Other pavement surfaces (coquina, gravel, oyster shell) suitable for use in lightly traveled areas.

### **Discharge Treatment**

Stormwater treatment unit operations should be applied at such a scale that they are less complex and less costly than treatment plant technology and can be used either independently or in conjunction with collected stormwater. Unit operations considered applicable may be the physical processes of settling, filtration, and screening, and the chemical processes of flocculation and disinfection.

66. Physical, chemical, biological, or mixed methods of treating stormwater runoff.

67. Wetlands - use natural freshwater wetland areas to modify urban pollutant loads. Wetlands, both natural and artificial, can act as a combination of detention basins and swales. As stormwater enters a wetland, its velocity diminishes and suspended solids settle to the bottom where they may be slowly eliminated through natural processes. Heavy metals may be adsorbed, petroleum hydrocarbons may be evaporated or degraded by bacteria, and nutrients such as phosphorus and nitrogen are taken up by wetland plants. The question remains whether the use of wetlands in stormwater management can adversely affect the wetlands themselves, as well as associated groundwater.

68. Maintenance of entire riparian corridor or greenway.

69. Rockreed microbial filter system.

Structural BMPs (e.g., retention basins) usually attempt to deal with stormwater problems at their source through artificially constructed systems. They are often used when vegetation alone will not provide the necessary degree of protection, or when flows concentrate in a specific area.

Nonstructural BMPs (e.g., grass swales) take into consideration site factors and use features of the natural drainage system, vegetative controls, and the modification of everyday land use practices to achieve similar ends. They may prove to be ineffective as remedial measures, but are best incorporated into designs of any future stormwater management system.

## 6 STORMWATER MANAGEMENT BMPS

### Water Quality Basins

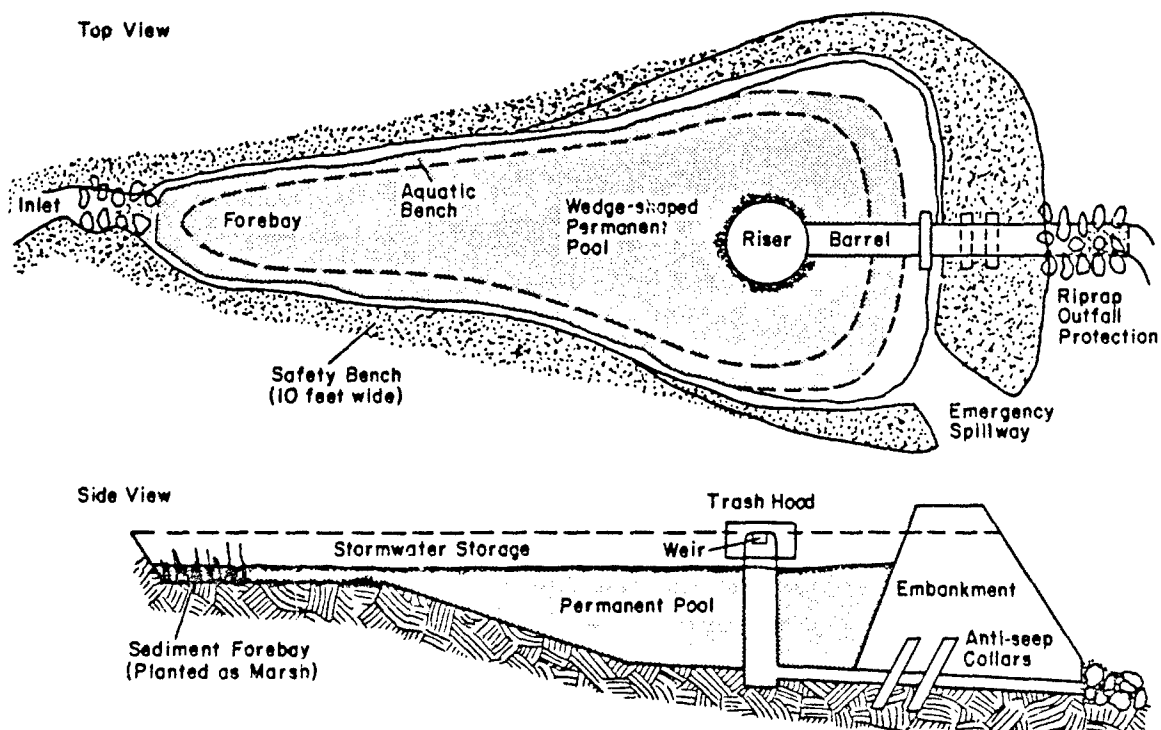
#### Detention/Retention Basins

##### *Description*

Detention/retention basins are impoundments that have a permanent pool of water, and have the capacity to temporarily store stormwater runoff. The capability to retain stormwater runoff has made detention/retention basins popular alternatives for flood control and stormwater management. The basins can also be used for water quality improvement alternatives, but additional planning and design considerations will need to be incorporated. Figure 7 shows a schematic diagram of a detention/retention basin.

##### *Target Pollutants*

Detention/retention basins are one of the most effective water quality BMPs. If properly designed and maintained, they can achieve high removal rates for sediment, BOD, organic nutrients, and trace metals. They can also provide partial removal of dissolved nutrients (i.e., dissolved phosphorous and Kjeldahl nitrogen).



(Source: Schueler, 1987. Used with permission.)

Figure 7. Schematic of a Detention/Retention Basin.

### *Effectiveness*

During a storm event, contaminated runoff enters a basin and displaces "old/clean" water, until contaminated runoff reaches the outlet structure of the basin. When the contaminated runoff reaches the outlet, the runoff will have been diluted by the water that was in the permanent pool. The process of dilution helps to reduce the concentration of contaminants in the outflow. After the storm event, fine suspended solids in the basins will have an extended period of time to settle out; the time for sedimentation will depend on the retention period of the basin and the time until the next storm event. In addition to the settling out of contaminants, the retention period of the stormwater runoff will also provide for partial removal of dissolved nutrients by biological uptake.<sup>10</sup>

The combination of dilution, biological uptake, and sedimentation results in fairly high pollutant removal rates for relatively small storm events. Runoff from larger storm events will receive some treatment, but not as much as for the smaller storm events.

Studies have shown that good control over the smaller storm events is more important to the long-term pollutant removal process. If a basin is properly planned, designed, and constructed, the long-term pollutant removal efficiencies illustrated in Figure 8 could be expected.

### *Planning Considerations*

**Site Suitability.** The site for a proposed detention/retention basin should have suitable soil conditions to prevent excessive seepage. Excessive seepage and evaporation losses from the basin could lead to large fluctuations in the elevation of the permanent pool. Although variation in the pool elevation will not necessarily reduce the effectiveness of the basin, it may not be acceptable aesthetically. If a basin is planned on a site with permeable soil conditions (i.e., sandy or silty soils), a compacted clay liner or a geotextile liner may be required.

**Minimum Drainage Area.** The drainage area above a basin must be of sufficient size to maintain the permanent pool. A general rule of thumb is that 4 acres of contributing watershed area are needed for each acre-foot of storage. For sites with small drainage areas, a supplemental water supply may be required if a permanent pool is desired.

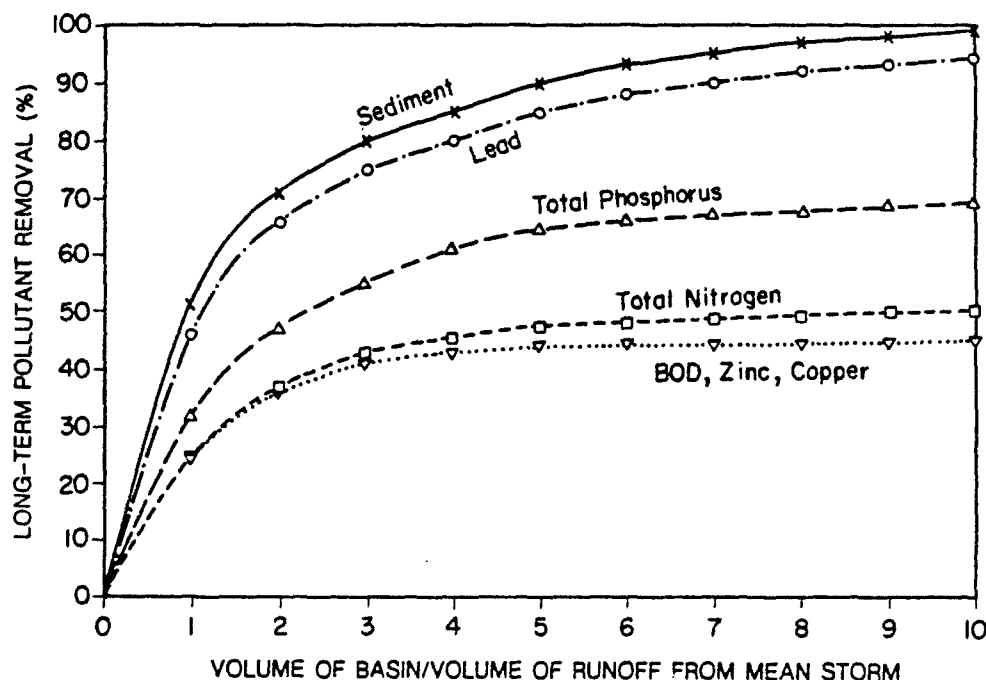
**Cost-effectiveness.** Detention/retention basins usually are not feasible BMPs in watersheds where land costs or space requirements are at a premium. In small watersheds, the basin and its buffer could consume as much as 10 percent of the total watershed area. Therefore, the construction of a basin could represent a significant capital investment and maintenance commitment. In general, regional basins with large drainage areas are more cost effective than on-site basins.

**Effects on Groundwater.** The impact of infiltration basins on groundwater were studied as part of the Nationwide Urban Runoff Program.<sup>11</sup> The study concluded that there was no significant impact to groundwater from infiltration basins. Since a detention/retention basin would be designed to discourage infiltration, the potential for groundwater contamination would be less than that for infiltration basins.

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<sup>10</sup> W.W. Walker, "Phosphorus Removal by Urban Runoff Detention Basins," *Lake and Reservoir Management, Volume 3* (North American Lake Management Society, Washington DC, 1987), pp 314-326.

<sup>11</sup> U.S. Environmental Protection Agency (USEPA) *Results of the Nationwide Urban Runoff Program*, NTIS Accession Number: PB84-185552 (USEPA, Water Planning Division, Washington DC, 1983).



NOTE: Average results from U.S. EPA (1986), and adapted to reflect modifications of Walker (1986).

(Source: Schueler, 1987. Used with permission.)

**Figure 8. Estimated Removal of Pollutants as a Function of Permanent Pool Size.**

In areas with shallow aquifers, however, there should be a minimum of 2 ft of soil between the basin and the aquifer to act as a seal and minimize seepage from the basin.

**Utility Relocation.** Most utility companies will not allow existing underground pipes to be submerged under a permanent pool of water. Locating a basin over existing underground pipes could lead to infiltration problems and make maintenance of the pipes extremely difficult. Therefore, if a basin is to be constructed, the site engineer should make sure that the basin does not cross any utility rights-of-way.

**Wetland Permits.** The best site for a detention/retention basin is a low-lying marshy area or a natural depression. Unfortunately, these areas are often classified as freshwater wetlands, and may be protected under state and Federal laws. The site engineer should consult the local wetland maps and the wetland permitting agencies to determine if the site has any wetlands within its boundaries. If the site has been identified to have wetlands, the site engineer will have to secure the required wetland permits before beginning basin construction.

#### *Design Recommendations*

**Pool Volume.** The size of the permanent pool in relation to the contributing watershed is probably the greatest factor influencing the pollutant removal rates in detention/retention basins. Larger basins remove pollutants better than smaller basins. The criteria that governs the minimum volume of the permanent pool varies from state to state. Therefore, when determining the minimum volume of the

permanent pool, the site engineer should follow the stormwater management regulations applicable to the site.

The recommendations presented in *Design Calculations for Wet Detention Ponds*<sup>12</sup> are considered adequate for most typical basins. The design criteria developed in that report are based on the results of the Nationwide Urban Runoff Program. This criteria states that the permanent pool should be equal to or greater than the runoff from a 2.0-in. rainfall event for fully developed watershed conditions. Use the recommended procedure in Chapter 8 of that report to determine the volume of runoff. The sediment storage volume must be added to the runoff volume to compute the total volume of the permanent pool.

**Depth of Basin.** Since much of the pollutant removal in a detention/retention basin is accomplished by gradual settling, the depth of the basin is an important aspect of the design. The average depth of the permanent pool can be determined by dividing the total volume of the pool by the surface area of the pool. The average depth of the permanent pool should be greater than 3 ft, but less than 9 ft.

If shallower depths are used, fine sediments may be resuspended by wind-generated currents. If depths of greater than 9 ft are used, the pond may be subject to temporary thermal stratification. Stratified ponds tend to become anoxic more frequently than shallower ponds, they don't have ideal settling characteristics, and they may release previously deposited pollutants that may be mixed back into the upper layer of the pond by wind-generated currents.

**Shape of Basin.** "Plug flow" conditions are desirable in a detention/retention basin to enhance water quality benefits. In an ideal plug flow situation, the volume of "clean" water within the permanent pool would be totally displaced before any stormwater runoff is discharged. This ideal condition cannot be obtained practically, but the basin could be designed to encourage plug flow conditions as much as possible.

The most effective shape of the basin to promote plug flow is to have a length-to-width ratio equal to 3.0 or greater. In some cases, baffles can be used to prevent short-circuiting in a basin with a small length-to-width ratio. Another alternative to increase plug flow characteristics is to construct two or more basins in series that have a total volume of the permanent pools equal to that described previously.

**Slopes of Basin.** For safety reasons and to promote the growth of rooted aquatic plants, a gently sloping bench should extend into the pool at least 10 ft. Shallow slopes make routine maintenance of the banks easier and safer, and allow for better access to the basin for maintenance. On the other hand, steeper slopes will provide for increased stormwater capacity per surface area.

The slopes of the basin will depend on the site constraints and economical trade offs imposed on the site engineer. In general, the bench should have a slope no steeper than 10:1, and beyond the bench, the slope of the basin should be no steeper than 3:1. The maximum slope that can be used may be limited by the stability of the natural soils.

**Aquatic Vegetation.** Establishing aquatic vegetation around the perimeter of a detention/retention basin will enhance the pollutant removal rates. The vegetation growing on the bench will serve to reduce the chance of shoreline erosion by wave action, provide habitat for wildlife, and help improve water quality. Although rooted aquatic vegetation obtains most of its nutrients from the bottom sediments, algae attached to the plants will help to remove some soluble nutrients. Shallow, organic-rich waters in the marshy fringe will provide an ideal environment for bacteria and other microorganisms that reduce organic

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<sup>12</sup> W.W. Walker, *Design Calculations for Wet Detention Ponds* (St. Paul Water Utility, St. Paul, MN, 1987).

matter and nutrients. The marshy fringe will also provide for a habitat for predacious insects that can serve as a natural control for mosquitos and other nuisance insects.

**Inlet And Outlet Protection.** To prevent erosion around the inlets, it is desirable to provide a forebay around each of the inlets. The forebays are designed to provide energy dissipation of the incoming water and to trap coarse sediments such as road sand. The inlets should also be designed so that the invert elevation is set at or below the surface of the permanent pool. To prevent the resuspension of basin sediments that had previously settled out, the inlets should be designed to minimize turbulence in the basin during inflow. Even relatively low velocities created in a basin during inflow can cause the resuspension of sediments.

The stream channel immediately downstream of the outlet of the basin should be lined with riprap to prevent erosion. Structural measures such as stilling basins can also be designed to reduce the velocity of the water discharged from the outlet structure. Floatable skimmers can be used to prevent floating debris from passing through the outlet structure and reaching the downstream receiving waters. (Refer to Chapter 7 for more information on floatable skimmers).

**Flood Routing.** Detention/retention basins must be designed to adequately convey flood waters for less frequent storm events (i.e., 5-yr event, 10-yr event, etc.). The criteria used to perform flood routing calculations will be subject to local and state regulations. Therefore, the site engineer responsible for the basin design should follow the local stormwater management regulations applicable to the design. The routing of flood waters will be based on the permanent pool volume and the release rate from the outlet structure.

Detention/retention basins should be designed to have a principal spillway and an emergency spillway. The principal spillway should convey the stormwater runoff from the design storm event, and the emergency spillway should convey the maximum storm event. The basin should have a minimum of 1 ft of freeboard (freeboard is the difference between the water surface elevation and maximum elevation of the vegetated embankments). In all designs, the site engineer must follow the local and state dam safety regulations.

**Structural Design.** All embankments, spillways, etc. should be designed in accordance with SCS Standard 378, Ponds.<sup>13</sup> Construction should be in accordance with appropriate construction and material specifications.

### *Maintenance*

The maintenance of detention/retention basins can be characterized by two distinct categories: routine and nonroutine. Routine maintenance practices include repairing eroded areas, mowing grass, removing debris, and nuisance (insects, weeds, odors, and algae) control. Maintenance inspections should be used to identify any routine maintenance requirements. Nonroutine maintenance practices include sediment cleanout and structural repairs.

**Routine Maintenance/Mowing:** The side slopes, embankment, and emergency spillway of a detention/retention basin should be mowed at least twice each year to prevent woody growth and provide weed control. Additional mowing may be required in residential areas for aesthetic reasons. The use of native or introduced grasses that are water tolerant and slow growing is recommended wherever possible. Mowing could constitute the largest routine maintenance expense.

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<sup>13</sup> *Field Office Technical Guide*, Section 4, Practice Standard No. 378, Ponds (U.S. Department of Agriculture/Soil Conservation Service [USDA/SCS], 1977).

**Inspections.** Detention/retention basins need to be inspected annually to ensure that the basin operates as it was designed. Inspections should be conducted during the wet weather seasons to determine if the basin is functioning properly. An inspection should include checking the following:

1. Embankment for subsidence, erosion, and tree growth.
2. Condition of the emergency spillway and drain.
3. Accumulation of sediments clogging outlets.
4. Adequacy of upstream and downstream channel, erosion protection measures.
5. Stability of the side slopes.

**Removal of Debris.** Debris and litter should be removed from the surface of the permanent pool as part of the periodic mowing operations. Particular attention should be paid to floatable debris around the outlet structure. The outlet structure should also be checked for any possible clogging.

**Erosion Control.** The side slopes, embankment, and emergency spillway of the basin may periodically suffer from extensive erosion. Corrective practices such as regrading and revegetation may be required. Additionally, the riprap protection used around the inlet pipes and the channel near the outlet structure may need to be repaired or replaced.

**Nuisance Control.** The control of insects, weeds, odors, and algae may be required in some basins. The demand for nuisance control measures is most frequent when the basin is close to residential developments. If the basin is properly designed and constructed, nuisance problems should be infrequent except under extremely dry weather conditions. The corrective practices available for nuisance control include biological and chemical control measures. Generally, biological control of algae and mosquitos by the use of certain fish species, is preferable over chemical control measures.

**Nonroutine Maintenance and Structural Repairs.** Deterioration of the various inlet/outlet structures in a detention/retention basin will require repair or replacement. The replacement costs are difficult to estimate, but will most likely constitute a significant future expense.

Water seeping through the embankment can be extremely difficult and expensive to correct. Water seepage could lead to internal erosion of the embankment, which could create instability within the embankment. To prevent the problems associated with internal erosion, the embankments should be constructed out of well-compacted clayey soils; antiseep collars should be installed around any barrel pipes.

**Sediment Removal.** If properly designed and constructed, detention/retention basins will eventually accumulate enough sediment to significantly reduce the storage capacity of the permanent pool. The best available estimate is that approximately 1 percent of the storage volume associated with the 2-year design storm could be lost annually. Smaller, stabilized watersheds will accumulate sediment at lower rates, while watersheds with unprotected channels will accumulate sediments at higher rates. The accumulation of sediment can lead to a degraded appearance and reduced pollutant removal of the basin. Therefore, a sediment removal program is frequently recommended with the design of detention/retention basins.



Cleaning sediment out of detention/retention basins can be very costly. A review of pond dredging in northern Virginia found that the average dredging cost was approximately \$14 per cubic yard (cu yd), with a range of \$6.25 to \$22.40.<sup>14</sup> The variation in these costs is due to the differences in the size of the basins, methods used to excavate and transport the sediment, and the proximity of the disposal sites. Sediment removal costs could be even higher if tipping fees are required at the disposal site.

Hauling sediments can increase typical disposal costs by \$5 to \$10/cu yd, depending on the travel distance. Therefore, disposing of sediments onsite and adjacent to the basins is recommended whenever possible. Disposing of sediments onsite will help reduce expected maintenance costs. Another alternative to help reduce maintenance costs is to design and construct additional sediment storage capacity into the detention/retention basin. The additional sediment storage capacity will increase the sediment cleanout cycle period, thereby reducing the number of times the basin will have to be cleaned out.

The presence of contaminants in basin sediments will require careful consideration of disposal methods.<sup>15</sup> Accumulated sediment must be handled and disposed of in a manner that will not affect surface or groundwater. Generally, sediment should be disposed of in a location where it will be stable and not in contact with humans. When sediment is disposed of onsite, the sediment should be covered with at least 4 in. of topsoil and vegetated to prevent erosion. If high concentrations of contaminants are found in the sediments, special disposal procedures may be required to stabilize them. In all cases, the contaminated sediments must be disposed of in accordance with any applicable state or Federal waste disposal regulations.

**Maintenance Costs.** The annual cost for routine maintenance practices averages from \$300 to \$500 per maintained acre, including the basin and the surrounding buffer zones. The estimated annual cost for nonroutine maintenance practices varies between 1 and 2 percent of the construction cost of the basin. A recommended annual maintenance cost to cover the routine and unexpected expenses is 3 to 5 percent of the construction cost for the basin.

The following design considerations will help reduce maintenance costs.

1. Keep all slopes 3:1 or flatter so vegetation can be maintained easily.
2. Reduce mowing costs by managing the buffer zones as a meadow rather than a lawn.
3. Include trash racks in principal spillways to prevent clogging.
4. Prevent leakage through embankments by using antiseep collars around the barrel, and by compacting the embankment.
5. Use reinforced concrete pipes because of their longer lifespan.
6. Place extra fill on the embankments to account for future settling or subsidence.
7. Provide a draw down device to drain the permanent pool, allowing access to the entire basin.
8. Provide a minimum 10-ft wide vehicle access to the basin; the access should not be steeper than 5:1. The access should never cross an emergency spillway unless the spillway has been designed for this.

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<sup>14</sup> C. Wiegand, et al., "Cost of Urban Runoff Controls" *Urban Runoff Quality: Impact and Quality Enhancement Technology*, B. Urbonas and L.A. Roesner, eds. (American Society of Civil Engineers [ASCE], New York, NY, 1986), pp 366-381.

<sup>15</sup> A.E. Zanoni, "Characteristics and Treatability of Urban Runoff Residuals," *Water Research*, vol 20, no. 5 (1986), pp 651-659.

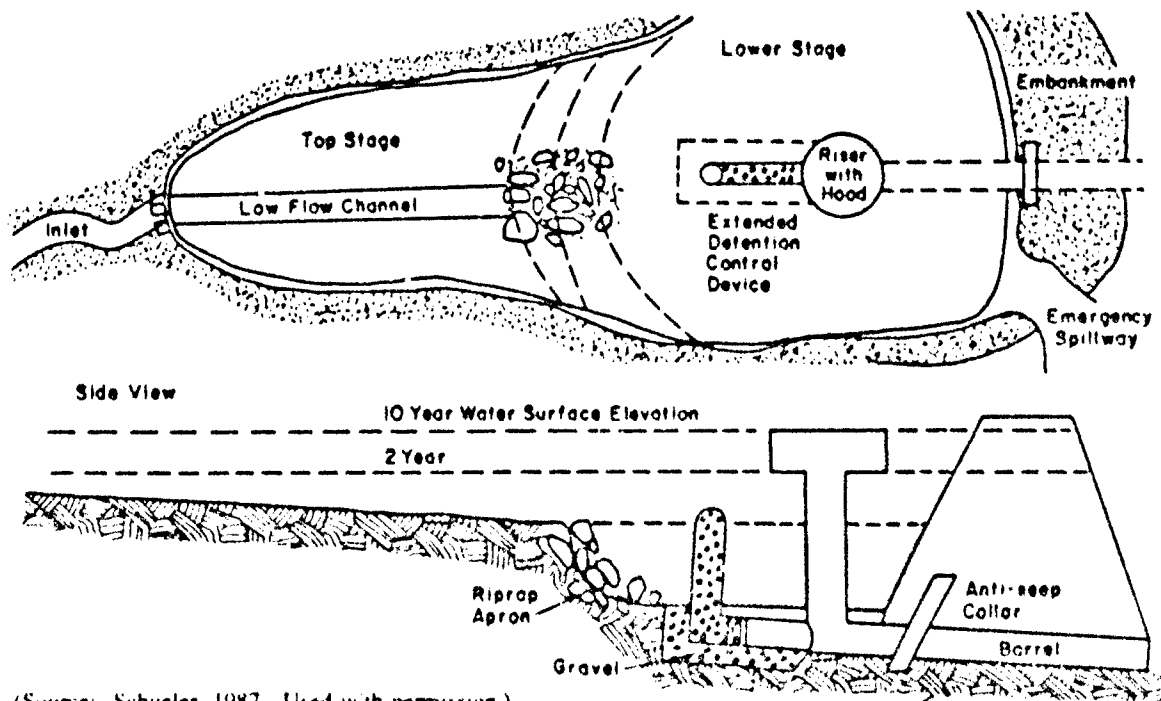
9. Provide onsite sediment disposal areas whenever possible. The disposal areas should be capable of receiving sediment from at least two cleanout cycles.

10. Provide extra sediment storage capacity within the basin. The additional storage capacity will come in the form of sediment forebays located at each of the inlets. Another alternative to increase the sediment storage capacity of the basin will be to increase the total volume of the permanent pool.

### Extended Detention Basins

#### *Description*

Extended detention basins are stormwater detention basins designed to temporarily hold stormwater for an extended period of time. Extended detention basins are different from detention basins because they can be normally dry, have a shallow marsh, or have a permanent pool. Extended detention basins are an effective, low cost way of removing particulate pollutants and controlling increases in downstream bank erosion. Extended detention basins are extremely cost-effective; construction costs are seldom more than 10 percent above the cost associated with conventional dry ponds. A schematic diagram of a dry extended detention basin is shown in Figure 9.



(Source: Schueler, 1987. Used with permission.)

Figure 9. Schematic of a Dry Extended Detention Basin.

## Target Pollutants

Extended detention basins can remove as much as 90 percent of particulate pollutants if the stormwater is detained for 24 hours or more. Therefore, sediment and the pollutants associated with the sediment (i.e., trace metals and nutrients) are the pollutants most effectively controlled by extended detention basins. Extended detention basins only slightly reduce the levels of soluble nutrients (i.e., phosphorous and nitrogen) found in urban runoff. The removal of dissolved pollutants can be enhanced by designing the basin to have a shallow marsh or a permanent pool. A schematic diagram of an extended detention basin with a marsh is shown in Figure 10. In addition to these pollutants being removed from the stormwater runoff, extended detention basins are very effective for controlling increases in downstream bank erosion and sediment loads.

## Effectiveness

Extended detention basins are fairly effective for removing particulate pollutants from stormwater runoff. The efficiency of an extended detention basin depends largely on the detention time. Most sediments associated with urban runoff will settle out within the first 6 hours of detention while the remaining sediments may take several days to settle out. Therefore, longer detention periods are desirable because ideal settling conditions usually do not develop in the basin for several hours.

The results of a laboratory study that showed that a majority of sediments settled out within the first 6 hours are shown in Figure 11. This study was based on a settling depth of 4 ft. Therefore, basins

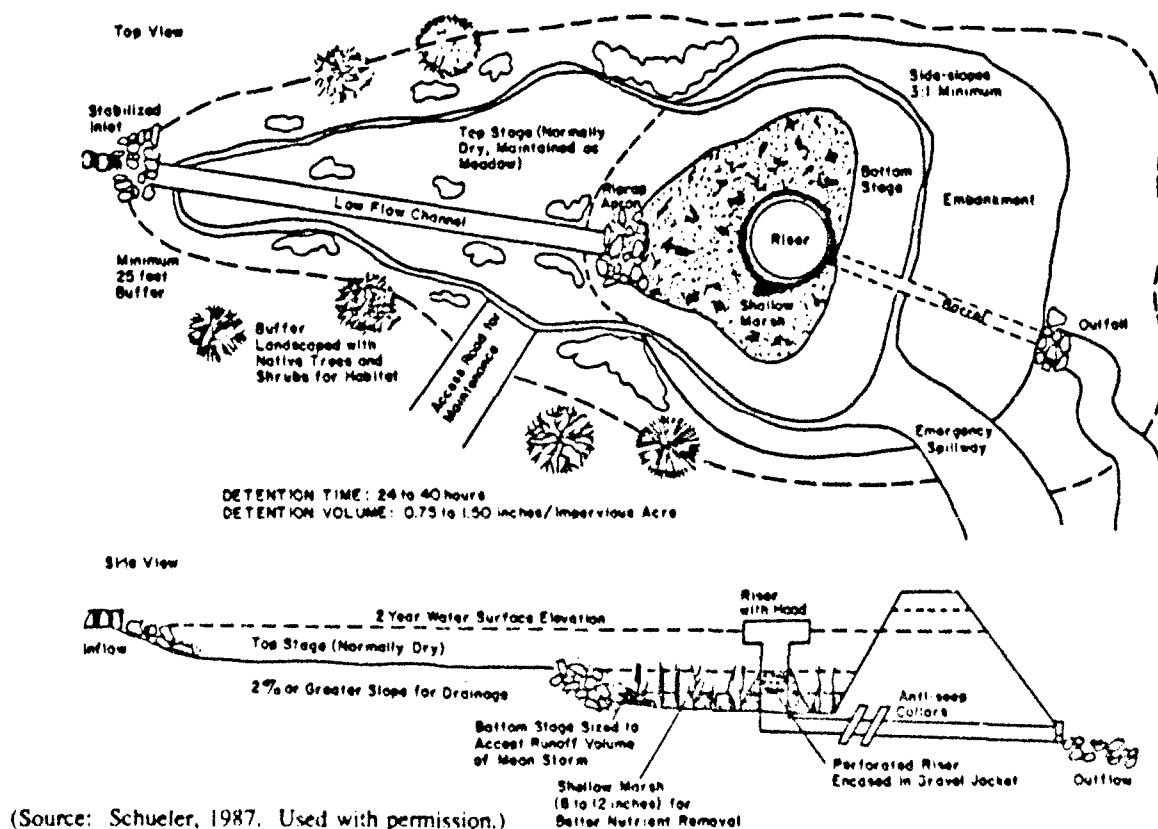


Figure 10. Schematic of an Extended Detention Basin With a Marsh.

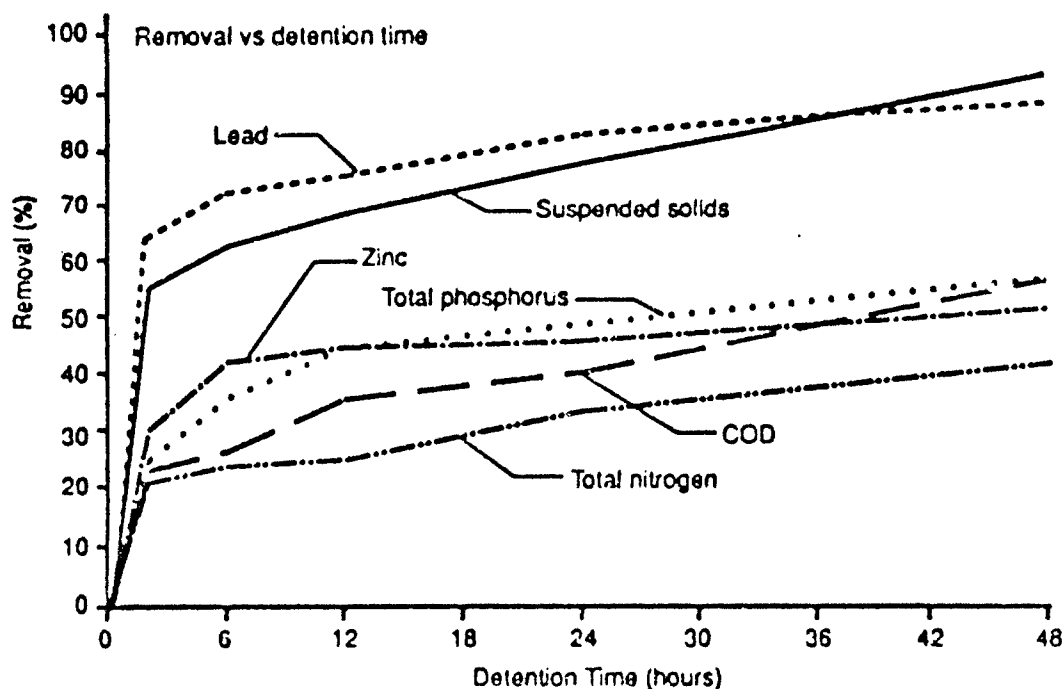
deeper than 4 ft would take longer to achieve the same pollutant rates. The results in Figure 11 can be used as an indicator of how effective a normally dry extended detention basin will be since the primary pollutant removal process involved is sedimentation.

Pollutants that have adhered to the sediment particulates will exhibit settling characteristics similar to that of sediment by itself. For example, lead will strongly adhere to sediment particulates; the lead removal curve will be similar to that of sediment. On the other hand, zinc will have a large portion of its load in the soluble form. Therefore, almost all of the zinc removed by extended detention is the minor portion that adheres to the sediment. If the bottom of the extended detention basin is designed and managed as a shallow marsh or permanent pool, biological and chemical transformations will provide for some removal of soluble nutrients.

Extended detention basins are effective in controlling the postdevelopment peak discharge rates to the desired predevelopment levels for a given design storm. Extended detention basins are also capable of managing smaller floods that contribute to channel erosion problems that occur more frequently than the annual or 2-year storm event. The outflow from an extended detention basin should be evaluated to determine if it is erosive. If the outflow from the extended detention basin exceeds the calculated discharge for the natural channel, the channel will start to erode when it reaches a bankflow condition. Therefore, the detention time of the stormwater runoff will have to be increased until the outflow from the basin is less than the channel discharge.

#### Planning Considerations

An extended detention basin is a suitable water quality practice when a permanent pool of water is not desired. The bottom of an extended detention basin may in fact be suitable for certain recreational



(Source: Schueler, 1987. Used with permission.)

Figure 11. Results of a Settling Column Study of Urban Stormwater Runoff.

activities if the basin is maintained in a normally dry condition. Therefore, an extended detention basin could provide adequate open space for development. Generally, the planning considerations associated with detention/retention basins are applicable to extended detention basins.

The lower stage of an extended detention basin can be designed in one of three ways: (1) normally dry, (2) having a shallow marsh, or (3) having a permanent pool of water.

Extended detention basins with a shallow marsh or permanent pool of water are more effective for pollutant removal than basins that are normally dry. The increased pollutant removal efficiency is caused by the better treatment of runoff from small runoff events.

Extended detention basins can be used in conjunction with an off-channel storage facility to improve water quality. The benefits to water quality from an off-channel facility depend on the design of the flow diversion device. To maximize water quality benefits, the diversion should send all flows from small events into the storage facility for treatment. Off-channel storage facilities designed to reduce peak storm event discharges in streams are normally designed so low flows are not detained.

To improve water quality, the stormwater runoff in an off-channel detention facility should be held for at least 24 hours. This period will allow a substantial percentage of suspended sediments to settle out. The amount of settling that takes place will depend on the depth of the impoundment and the length of time that favorable settling conditions are maintained. As the depth of water increases, the settling time will also increase. Therefore, the duration of the detention period will have to be increased proportionally as the depth of water increases in the basin.

#### *Design Recommendations*

Generally, the design recommendations for detention/retention basins are applicable to extended detention basins. The recommendations for detention/retention basins can be used to design the permanent pool, if a permanent pool is desired for the extended detention basin. In addition to the design recommendations for detention/retention basins, the recommendations below will be useful for designing extended detention basins.

**Detention Time.** A detention time of at least 24 hours is recommended to achieve the maximum removal of most pollutants from stormwater runoff. The majority of pollutants in stormwater runoff that can be removed by extended detention basins will be removed within the first 12 hours of detention. The additional detention time is recommended so adequate detention is provided after favorable settling conditions develop in the basin. Detention times longer than 24 hours may also be required to control downstream channel erosion problems.

The primary problem associated with designing extended detention basins involves the sizing of the control device used to provide adequate detention times for the entire range of storm events. If an extended detention basin is designed to store and release the 1-year storm event over a 24-hour period, stormwater runoff from smaller storm events may only be detained for a few hours and may not receive adequate treatment. Unfortunately, small storm events represent most of the annual stormwater runoff volume for the basin (Figure 12).<sup>16</sup> Therefore, the annual pollutant removal of the extended detention basin may be significantly reduced if small storm events are not adequately detained.

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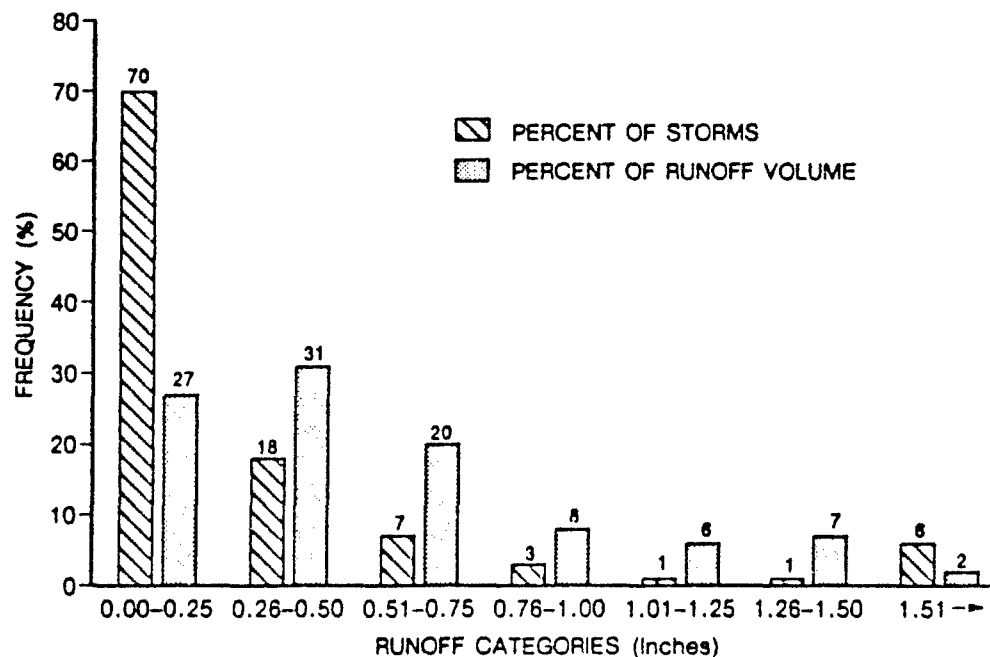
<sup>16</sup> T.R. Schueler.

Extended detention basins should be designed to provide an average detention time of 24 hours for the entire range of storm events expected each year. Stormwater runoff from very small storm events (0.1 to 0.2 in.) should be detained for a minimum of 6 hours. The detention of a wide range of storm events can be achieved by designing the outlet structure with more than one intake level and outlet rate.

**Storage Volume.** The volume of stormwater runoff detained will greatly influence the pollutant removal performance of an extended detention basin. At a minimum, extended detention basins should be designed to retain the "first flush" runoff volume and then discharge the runoff over a period of 24 hours or more. The first flush runoff volume can be considered as the runoff produced by a mean storm event, and preferably should be the runoff produced by a 1-in. storm event.

**Pond Configuration.** To improve pollutant removal and reduce maintenance requirements, it is recommended that extended detention basins be designed in a two-stage fashion (Figures 9 and 10). The upper stage of the basin is intended to be dry except during large, infrequent storm events. The lower stage is intended to accept regular inundation. The volume of the lower stage should be greater than the runoff volume for the mean storm event.

The lower stage is the primary location for pollutant removal. The lower stage should be designed to prevent the resuspension of previously deposited materials. One method of preventing resuspension is to design the lower stage to have either artificial wetlands to stabilize the sediments or a permanent pool. The two-stage design helps to reduce the velocity of stormwater runoff as it enters the lower stage, prevents concentrated flows, and improves the overall settling characteristics of the lower stage.



**Figure 12. Frequency Distribution of Runoff Events in a Moderately Developed Watershed.**  
(Based on Washington D.C. Area Data, With 300 Storms at 7 Sites).

The slopes in the basin should be flat enough so they are relatively easy to maintain. The side slopes of the basin should be no greater than 3:1; flatter slopes are recommended. The slope of the upper stage of an extended detention basin should be between 2 to 5 percent to facilitate rapid drainage.

**Pilot Channels.** Erosion will most likely occur within the low flow channel through the upper stage of an extended detention basin. To prevent erosion of the basin, a pilot channel should be provided. The pilot channel should be lined with riprap to stabilize the channel and should not extend to the outlet structure. If the pilot channel is extended to the outlet structure, pollutants will be delivered directly to the outlet and previously settled material will be resuspended. Therefore, the pilot channel should be extended only to the lip of the lower stage of the pond.

**Inlet And Outlet Protection.** To prevent erosion around the inlets, provide riprap around each of the inlets. The inlets also should be designed so the invert elevation is set at the surface elevation of the upper stage of the basin. Inlets that discharge above the elevation of the upper stage may cause erosion of the embankments.

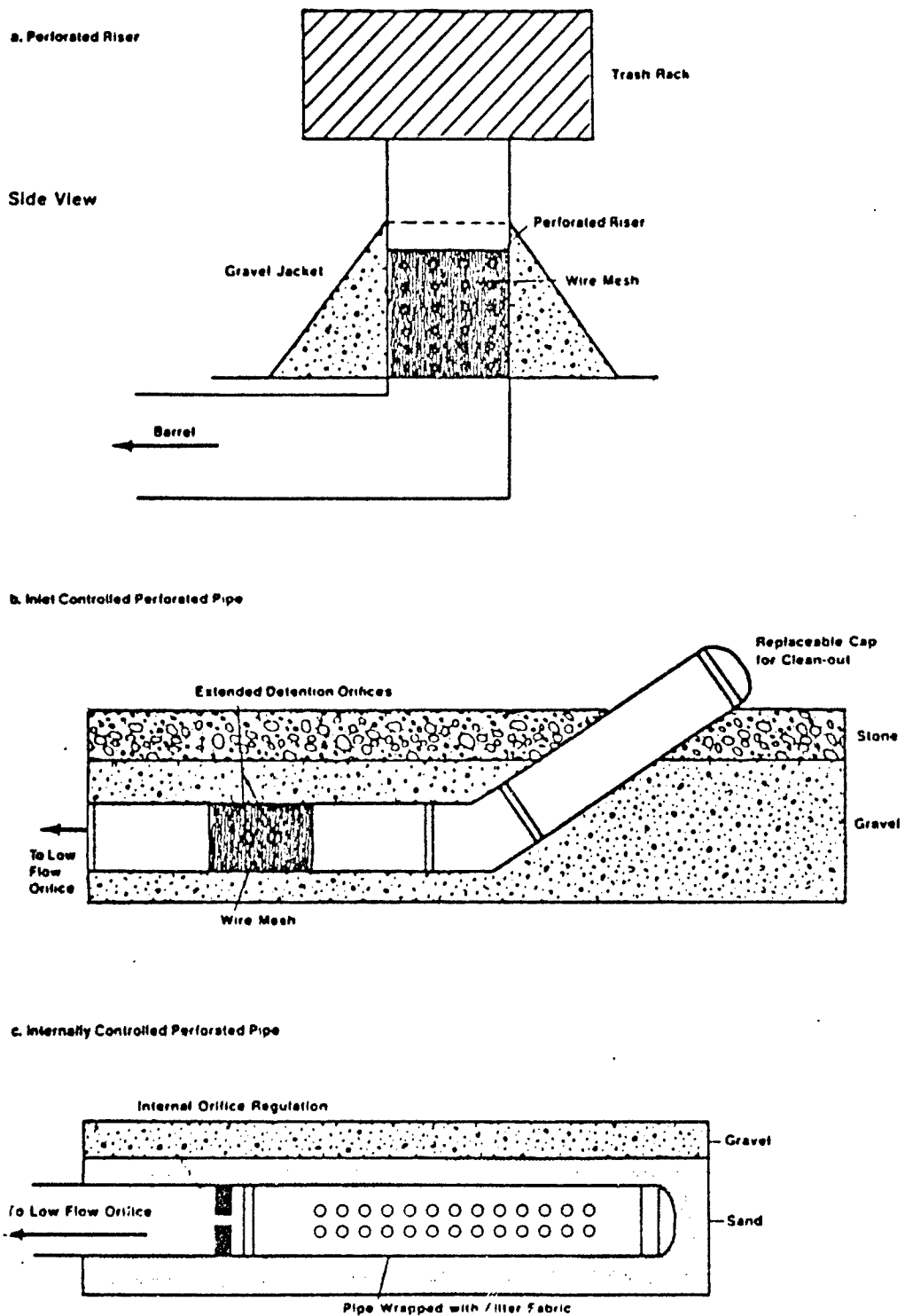
The stream channel immediately downstream of the basin should be lined with riprap to prevent channel erosion. Structural measures such as stilling basins can also be designed to reduce the velocity of the water discharging from the outlet structure.

**Flood Routing.** Extended detention basins must be designed to adequately convey flood waters for less frequent storm events (i.e., 5-yr event, 10-yr event, etc.). The criteria used to perform flood routing calculations is subject to local and state regulations. Therefore, the site engineer responsible for designing the basin should follow the local stormwater management regulations applicable to the design. The routing of flood waters will be based on the permanent pool volume and the release rate from the outlet structure.

Extended detention basins should be designed to have a principal spillway and an emergency spillway. The principal spillway should be designed to convey the stormwater runoff from the design storm event; the emergency spillway should be designed to convey the maximum storm event. The basin should be designed with a minimum of 1 ft of freeboard (freeboard is the difference between the water surface elevation and maximum elevation of the vegetated embankments). In all designs, the site engineer must follow the local and state dam safety regulations.

**Methods To Extend Detention Times.** The devices used to extend the detention time for extended detention basins are normally attached to the low flow orifice on the outlet structure or the riser. Some frequently used methods to extend detention times are shown in Figures 13 and 14, and are listed below:

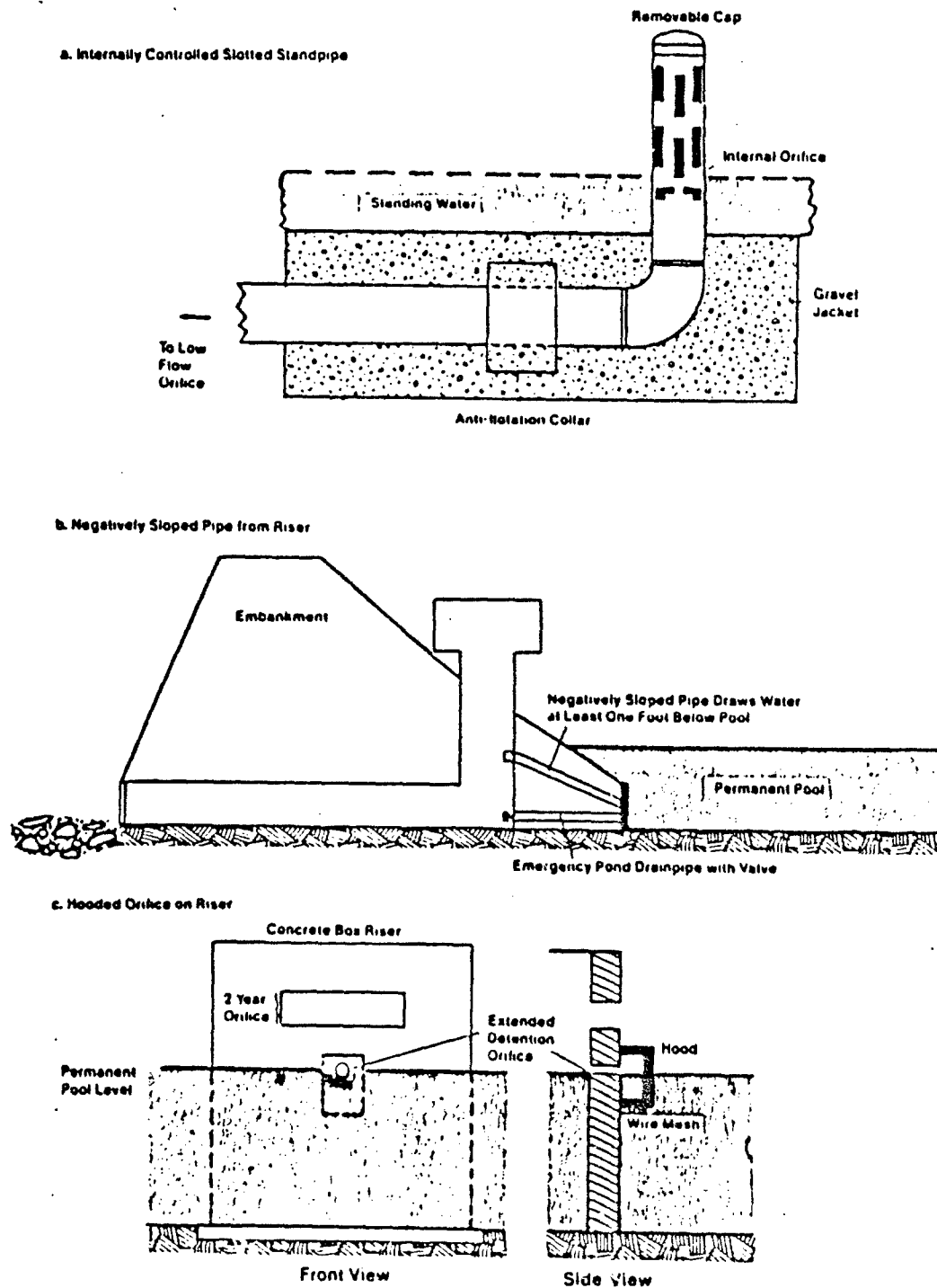
1. Perforated riser enclosed in a gravel jacket (Figure 13a).
2. Perforated extension of low flow orifice inlet control (Figure 13b).
3. Perforated extension of low flow orifice, outlet control (Figure 13c).
4. Slotted standpipe from low flow orifice inlet control (Figure 14a).
5. Negatively sloped pipe from riser (Figure 14b).
6. Hooded riser (Figure 14c).



(Source: Schueler, 1987. Used with permission.)

Figure 13. Methods for Extending Detention Times in Dry Basins.





(Source: Schueler, 1987. Used with permission.)

Figure 14. Methods for Extending Detention Times in Wet Basins.

**Structural Design.** All embankments, spillways, etc., should be designed in accordance with the *SCS Field Office Technical Guide*. Construction should be in accordance with appropriate construction and material specifications.

### *Maintenance*

The maintenance of extended detention basins can be characterized by two distinct categories: routine and nonroutine. Routine maintenance practices include repairing eroded areas, mowing grass, removing debris, and nuisance (insects, weeds, odors, and algae) control. Maintenance inspections should be used to identify any routine maintenance requirements. Nonroutine maintenance practices include sediment cleanout and structural repairs.

**Routine Maintenance/Mowing.** The upper stage, side slopes, embankment, and emergency spillway of an extended detention basin should be mowed at least twice each year to prevent woody growth and provide weed control. Additional mowing may be required in residential areas for aesthetic reasons. The use of native or introduced grasses that are water tolerant and slow growing is recommended wherever possible. Mowing could constitute the largest routine maintenance expense.

**Inspections.** Extended detention basins need to be inspected annually to ensure that the basin operates as it was designed. Inspections should be conducted during the wet weather seasons to determine if the basin is functioning properly. An inspection should include checking the following:

1. Embankments for subsidence, erosion, and tree growth.
2. Condition of the emergency spillway and drain.
3. Accumulation of sediments clogging outlets.
4. Adequacy of upstream and downstream channel erosion protection measures.
5. Erosion of the basin's beds and banks.
6. Erosion of pilot channels.
7. Outlet structure for evidence of clogging or for release that is too rapid.

**Removal of Debris.** Debris and litter should be removed during regular mowing. Particular attention should be paid to floatable debris around the outlet structure. The outlet structure should be checked for any possible clogging.

**Erosion Control.** The side slopes, embankment, emergency spillway, and upper stage of the basin may periodically suffer from extensive erosion. Corrective practices such as regrading and revegetation may be required. Additionally, the riprap protection used around the inlet pipes and the channel near the outlet structure may need to be repaired or replaced.

**Nuisance Control.** The control of insects, weeds, odors, and algae may be required in some basins. The demand for nuisance control measures is most frequent when the basin is close to residential developments. If the basin is properly designed and constructed, nuisance problems should be infrequent except under extremely dry weather conditions. The corrective practices available for nuisance control include biological and chemical control measures. Generally, biological control of algae and mosquitos by the use of certain fish species is preferable over chemical control measures.

**Nonroutine Maintenance and Structural Repairs.** Deterioration of the various inlet/outlet structures in a detention/retention basin will require repair or replacement. The replacement costs are difficult to estimate, but will most likely constitute a significant future expense.

Water seeping through the embankment can be extremely difficult and expensive to correct. Water seepage could lead to internal erosion of the embankment, which could create instability within the embankment. To prevent the problems associated with internal erosion, the embankments should be constructed out of well-compacted clayey soils; antiseep collars should be installed around any barrel pipes.

**Sediment Removal.** If properly designed and constructed, extended detention basins will eventually accumulate enough sediment to significantly reduce the storage capacity of the permanent pool. The best available estimate is that approximately 1 percent of the storage volume associated with the 2-year design storm could be lost annually. Smaller, stabilized watersheds will accumulate sediment at lower rates, while watersheds with unprotected channels will accumulate sediments at higher rates. The accumulation of sediment can lead to a degraded appearance and reduced pollutant removal of the basin. Therefore, a sediment removal program is frequently recommended with the design of extended detention basins.

Cleaning sediment out of extended detention basins can be very costly. A review of pond dredging in northern Virginia found that the average dredging cost was approximately \$14/cu yd, with a range of \$6.25 to \$22.40/cu yd.<sup>17</sup> The variation in these costs is due to the differences in the size of the basins, methods used to excavate and transport the sediment, and the proximity of the disposal sites. Sediment removal costs could be even higher if tipping fees are required at the disposal site.

Hauling sediments can increase typical disposal costs by \$5 to \$10/cu yd, depending on the travel distance. Therefore, disposing of sediments onsite and adjacent to the basins is recommended whenever possible. Disposing of sediments onsite will help reduce expected maintenance costs. Another alternative to help reduce maintenance costs is to design and construct additional sediment storage capacity into the extended detention basin. The additional sediment storage capacity will increase the sediment cleanout cycle period, thereby reducing the number of times the basin will have to be cleaned out.

The presence of contaminants in basin sediments will require careful consideration of disposal methods.<sup>18</sup> Accumulated sediment must be handled and disposed of in a manner that will not affect surface or groundwater. Generally, sediment should be disposed of in a location where it will be stable and not in contact with humans. When sediment is disposed of onsite, the sediment should be covered with at least 4 in. of topsoil and vegetated to prevent erosion. If high concentrations of contaminant are found in the sediments, special disposal procedures may be required to stabilize them. In all cases, the contaminated sediments must be disposed of in accordance with all applicable waste disposal regulations.

**Maintenance Costs.** The annual cost for routine maintenance practices averages from \$300 to \$500 per maintained acre, including the basin and the surrounding buffer zones. The estimated annual cost for nonroutine maintenance practices varies between 1 and 2 percent of the construction cost of the basin. A recommended annual maintenance cost to cover the routine and nonroutine expenses is 3 to 5 percent of the construction cost for the basin.

The following design considerations will help reduce maintenance costs.

1. The pond should have a two-stage design with a top stage (2 to 5 percent grade) draining to a level lower stage.

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<sup>17</sup> C. Wiegand, et al.

<sup>18</sup> A.E. Zanoni.

2. For easier mowing, keep all side slopes no steeper than 3:1 and no flatter than 20:1.
3. Surround all extended detention control devices with a properly designed filter.
4. Prevent leakage through embankments by using antiseep collars around the barrel, and by compacting the embankment.
5. Mowing costs can be reduced if the buffer zones are managed as a meadow rather than a lawn.
6. Place extra fill on the embankments to account for future settling or subsidence.
7. Provide a draw down device to drain the permanent pool, to access the entire basin.
8. Provide a minimum 10-ft wide vehicle access to the basin; the access should not be steeper than 5:1. The access should never cross an emergency spillway unless the spillway has been designed for it.
9. Provide onsite sediment disposal areas whenever possible. The disposal areas should be capable of receiving sediment from at least two cleanout cycles.
10. Provide extra sediment storage capacity within the basin by enlarging the lower stage of the basin or by including a permanent pool.

## **Infiltration Trenches**

### *Description*

An infiltration trench is a shallow excavation (3 to 8 ft) that has been backfilled with coarse stone aggregate to create an underground reservoir. Stormwater runoff is diverted into the trench where the runoff is temporarily stored in the void space between the aggregate. The stormwater runoff will then either infiltrate into the underlying soils or be collected by perforated underdrain pipes and routed to an outlet structure. A schematic diagram of a typical infiltration trench is shown in Figure 15.

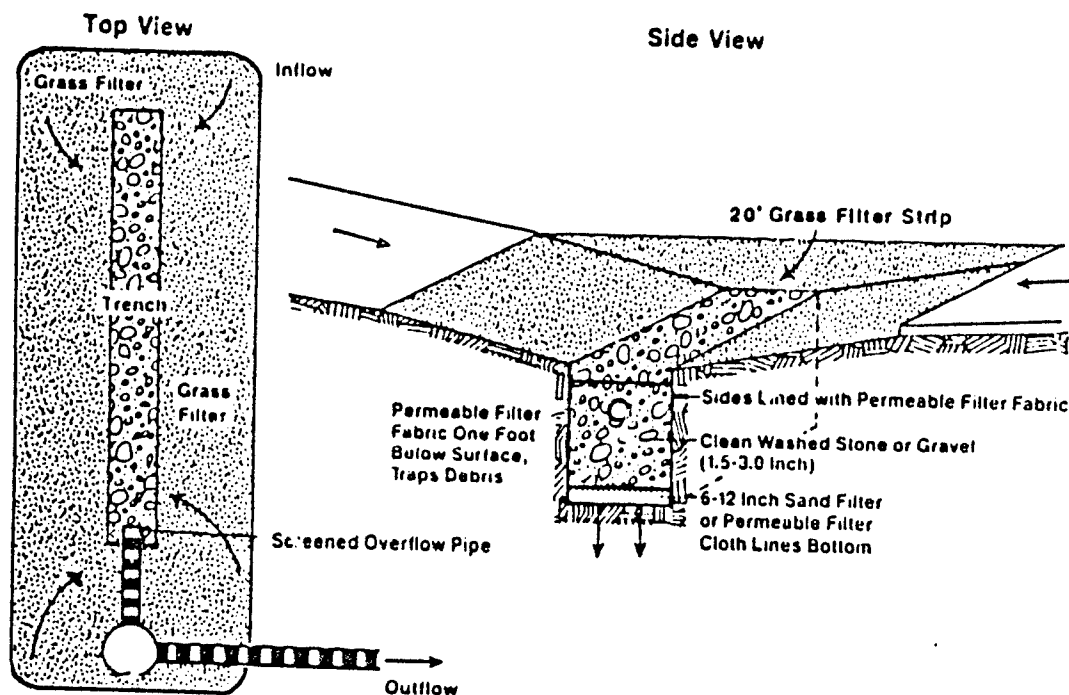
### *Target Pollutants*

Infiltration trenches are effective BMPs used to control both soluble and particulate pollutants in the stormwater runoff that enters the trenches. They are not intended to control coarse sediments or heavy concentrations of fine sediments, which clog the trenches. Filter strips or special inlets will have to be designated and constructed to prevent the sediments in stormwater runoff from entering and clogging the infiltration trenches.

Fine particulates and soluble pollutants can be removed effectively after the stormwater infiltrates through the trench and into the underlying soils. The underlying soil layer has been shown to be a highly effective and normally safe means of removing stormwater runoff pollutants.<sup>19</sup> Table 2 provides some estimates of pollutant removal rates that can be expected for complete infiltration systems.<sup>20</sup> A complete infiltration system is defined as a system where stormwater runoff can exit the trench only by the process of infiltration.

<sup>19</sup> Metropolitan Washington Council of Governments (MWWOG) *Controlling Stormwater Runoff in Developing Areas Selected Best Management Practices*. (Water Resources Planning Board, 1979).

<sup>20</sup> U.S. Environmental Protection Agency (USEPA). *Process Design Manual for Land Treatment of Municipal Wastewater*, EPA-625/1-77-008, (USEPA, Washington, DC, 1977).



(Source: Schueler, 1987. Used with permission.)

Figure 15. A Typical Median Strip Infiltration Trench.

Table 2

Estimated Long-Term Pollutant Removal Rates for Full Infiltration Trenches

Urban Pollutant	Removal Rate (%)	Limiting Factor
Sediment	99%	Should actually be trapped before reaching the trench.
Total Phosphorus	65-75%	Leaching of remineralized organic phosphorus.
Total Nitrogen	60-70%	Leaching of soluble nitrate.
Trace Metals	95-99%	Behavior similar to sediment.
BOD	90%	Leaching of dissolved organic matter.
Bacteria	98%	Straining.

### *Effectiveness*

The effectiveness of infiltration trenches depends on their design and construction. As stormwater runoff enters a trench, many pollutants will be trapped or treated as the runoff infiltrates into the underlying soils. Stormwater runoff that bypasses the trench will be conveyed downstream untreated. Therefore, infiltration trenches could be described by three categories:

1. Complete infiltration systems.
2. Partial infiltration systems.
3. Water quality infiltration systems.

The three categories will differ in the volume of runoff stored/treated and the volume of runoff that bypasses, untreated. Complete infiltration systems are designed to accommodate the entire runoff volume for the design storm; the entire runoff volume will be treated as the runoff infiltrates into the underlying soils. Conversely, water quality infiltration systems are designed to treat only the first flush of the runoff volume during a storm; the remaining runoff will not be treated by the trench. The three categories of infiltration trenches can also be designed to reduce the peak discharge volume from a site of limited area. The reduction in the discharge volume will effectively reduce the effects of downstream erosion.

### *Planning Considerations*

Infiltration trenches are primarily onsite control structures, and are seldom used on drainage areas larger than 5 to 10 acres. Infiltration trenches can be used to control stormwater runoff from parking lots, rooftops, residential lots, etc. They can be designed and constructed as surface trenches or underground trenches. Surface trenches accept diffuse runoff directly from the adjacent drainage areas. Underground trenches accept concentrated runoff from pipes and storm drains. Several examples of surface and underground trench designs are shown in Figures 15 to 22.

Infiltration trenches are not feasible for sites with soils that have infiltration rates of less than 0.27 in./hr or any soil with a clay content greater than 30 percent. The seasonal highwater table should be at least 2 to 4 ft below the bottom of the trench. Trenches in commercial and industrial areas should also be at least 100 ft away from any drinking water wells, and should be located at least 10 ft downgradient and 100 ft upgradient from building foundations. In all cases, infiltration trenches must be designed to prevent any potential groundwater contamination.

Infiltration trenches generally should be restricted to sites with drainage areas less than 5 acres. They should not be used in locations that will be receiving high sediment loads that could clog the trenches. To minimize the sediment loads, a vegetative filter strip of about 20 ft should be designed to treat stormwater runoff before it reaches an infiltration basin.

### *Design Recommendations*

**Surface Trenches.** Surface trenches are typically used in residential areas where small sediment loads and small amounts of oil enter the trenches. Because the surface of the trenches are exposed, they have a higher risk of clogging than underground trenches. They are also more easily maintained and inspected.

A few of the typical surface trench designs that could be used include:

1. Median strip designs (Figure 15).
2. Perimeter parking lot designs (Figure 16).
3. Scale designs (Figure 17).

**Underground Trenches.** Underground trenches can be used in a variety of development situations. Underground trenches are primarily designed to handle concentrated flows from stormwater runoff. The impermeable cover helps to minimize clogging. However, the stormwater runoff entering the underground trenches should be pretreated to remove most of the sediments in the runoff before it enters the trench. The concentrated flows from the stormwater runoff should be evenly distributed throughout the trench. In general, underground trenches are designed to be more aesthetically pleasing, but they are more difficult and costly to maintain. A few of the typical underground trench designs that could be used include:

1. Over-sized pipe trench (Figure 18).
2. Underground trench with oil/grease inlet (Figure 19).
3. Under the swale designs (Figure 20).
4. Dry well designs (Figure 21).
5. Off-line trench system (Figure 22).

**Storage Volume.** A recommended storage volume for underground trenches will accommodate the runoff from 1 in. of rainfall. Additional storage capacity could be used if greater control of runoff volume or peak discharge is desired. The storage volume of an infiltration trench is provided by the void space between the coarse stone aggregate used as backfill material. The backfill material should be specified to have a void ratio between 30 and 40 percent. The void ratio is the ratio of the volume of voids to the total volume for a given sample of backfill material. Therefore, the storage volume of an infiltration trench is equal to the total volume of the trench multiplied by the void ratio of the backfill material.

**Storage Time.** An infiltration trench should be designed to drain completely within 3 days after a storm event. The combination of storage time, storage volume, and infiltration rate could be used to determine the maximum trench depth. Deeper trenches will have storage times greater than 3 days. Table 3 represents the maximum trench depth for various infiltration rates, where the void ratio of the backfill material remains at a constant value of 0.40.

**Runoff Filtering.** Oil, grease, floating organic matter, and suspended soils should be removed from stormwater runoff before it enters an infiltration trench. Oil/grease separators and vegetated filter strips could be used to remove these pollutants.

**Construction.** Infiltration trenches should not be constructed before the entire site is stabilized. If a trench is constructed before the site is stabilized, the sediment loads associated with construction practices will eventually clog the trench. Therefore, the backfill material would have to be excavated and replaced in order for the trench to perform adequately. Infiltration trenches should be lined with filter fabric to prevent the underlying soils from intruding into the coarse stone aggregate. It is recommended that an observation well be installed in each trench to monitor performance.

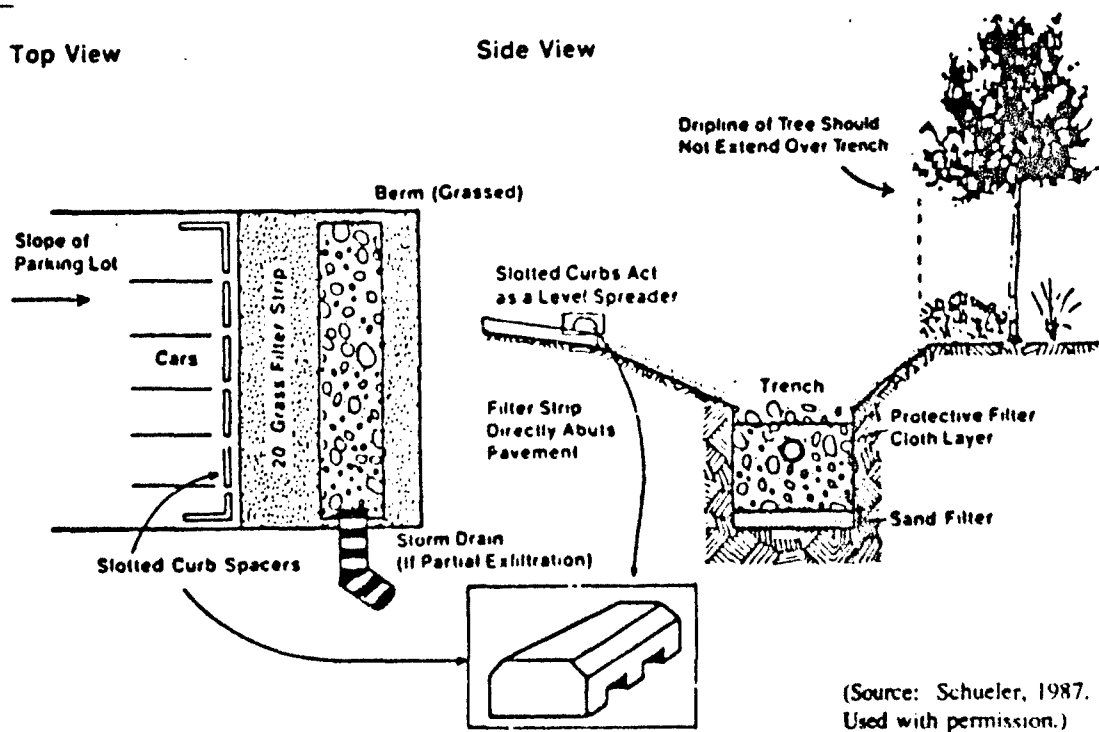


Figure 16. A Typical Perimeter Parking Lot Infiltration Trench.

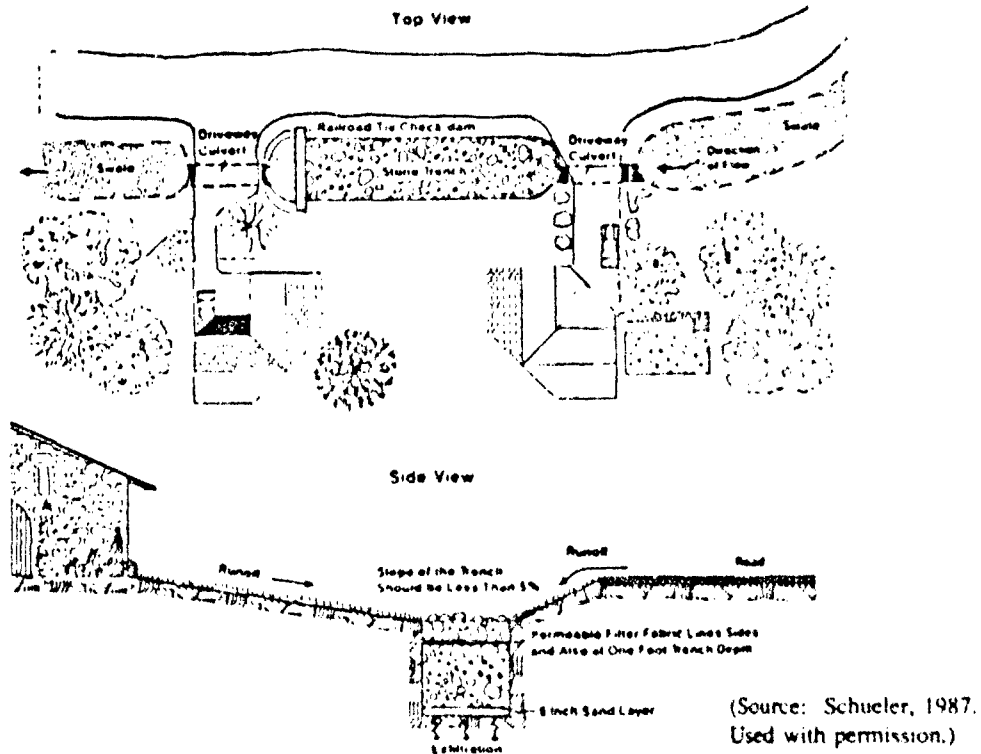
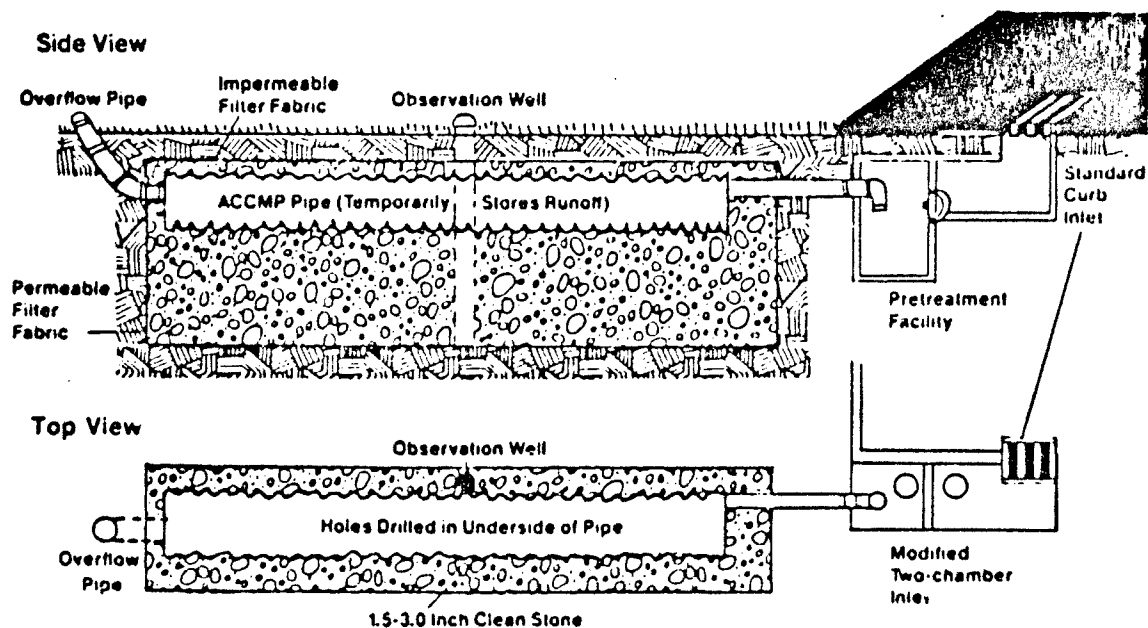


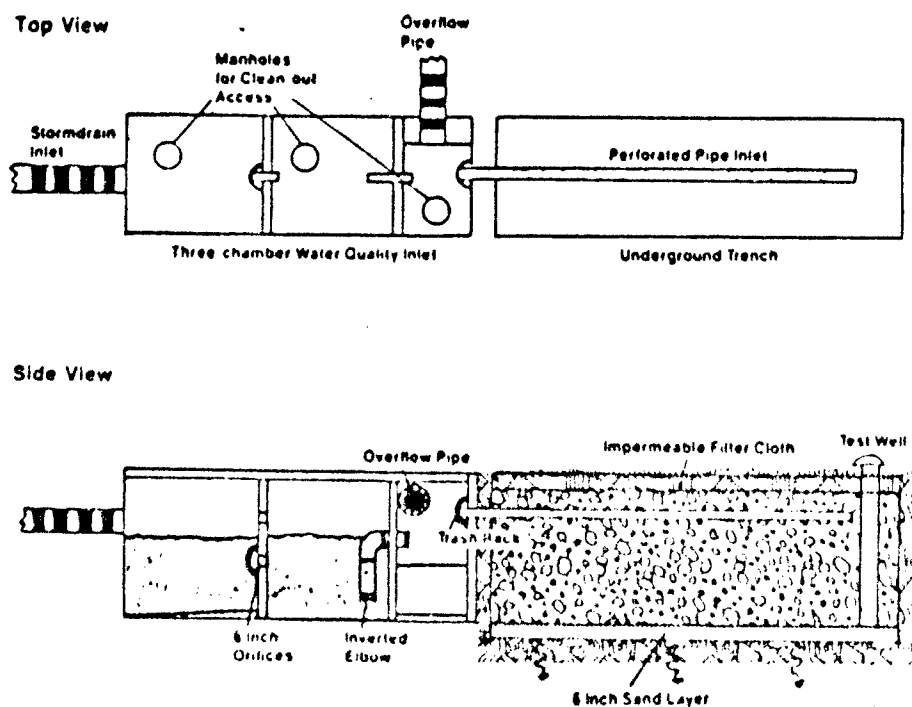
Figure 17. A Typical Vegetated Swale Infiltration Trench.





(Source: Schueler, 1987. Used with permission.)

Figure 18. A Typical Oversized Pipe Infiltration Trench.



(Source: Schueler, 1987. Used with permission.)

Figure 19. A Typical Underground Infiltration Trench With an Oil/Grease Chamber.

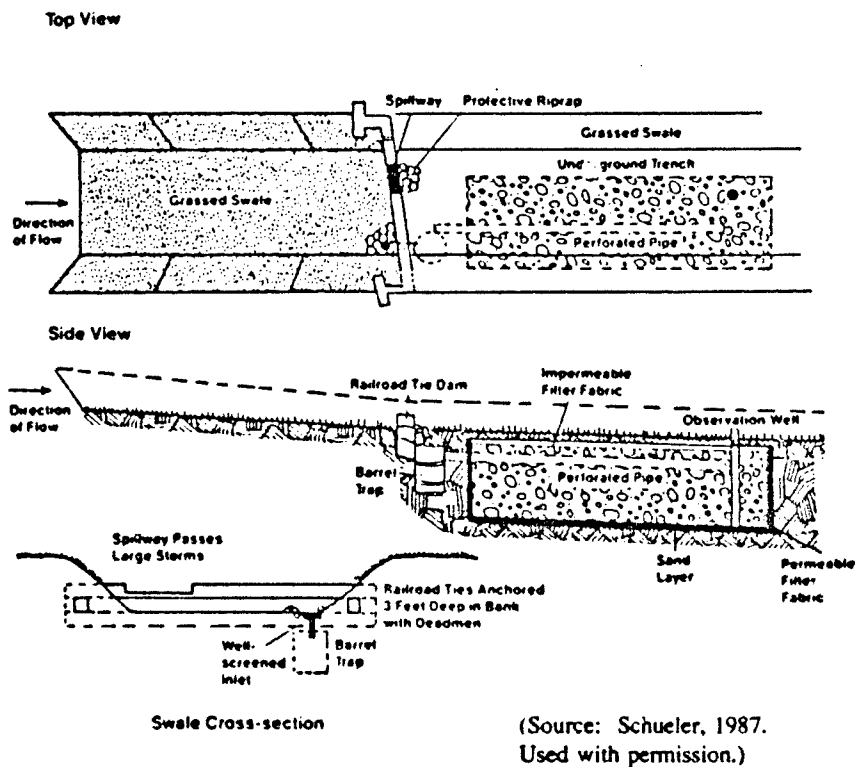


Figure 20. A Typical Under-the-swale Infiltration Trench.

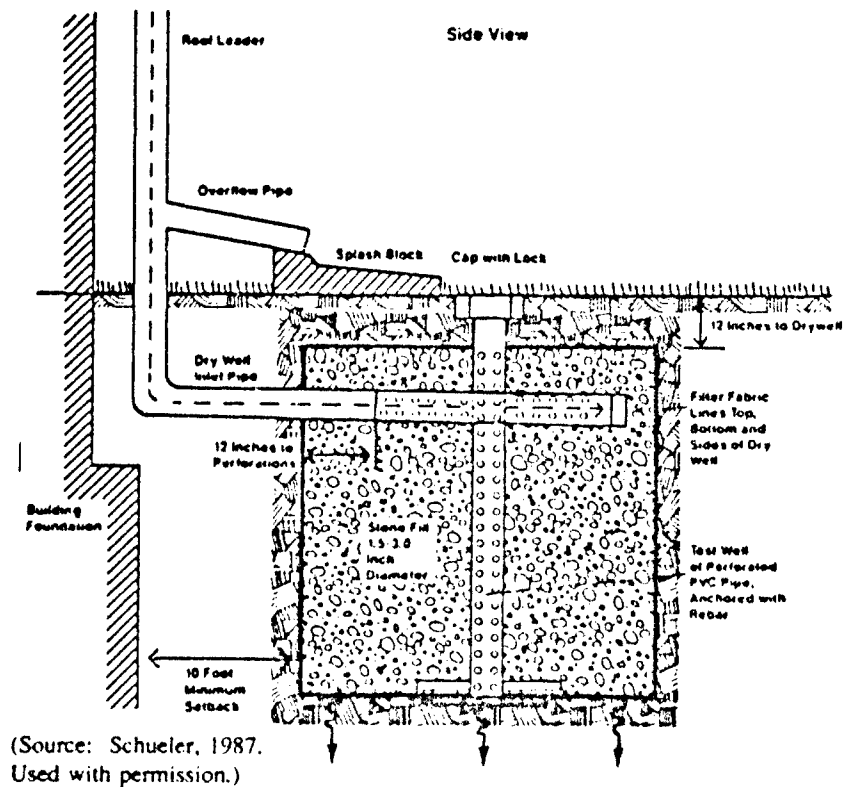
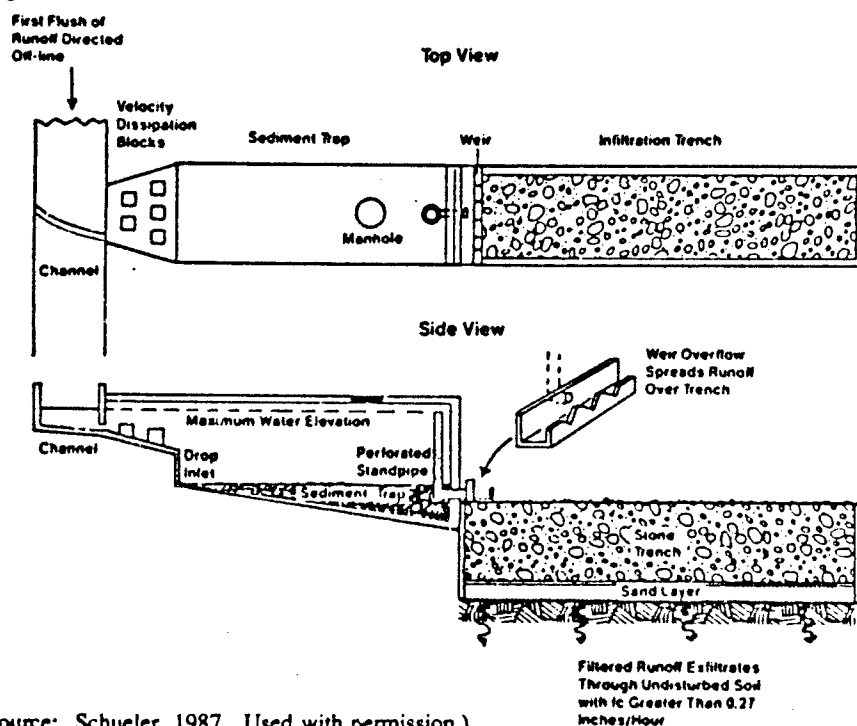


Figure 21. A Typical Dry Well.



(Source: Schueler, 1987. Used with permission.)

**Figure 22. A Typical Off-line Infiltration Trench System.**

### *Maintenance*

Maintenance of infiltration trenches can be characterized by two distinct categories: routine and nonroutine maintenance practices. Routine maintenance practices include mowing, buffer maintenance, sediment removal, and tree pruning. Maintenance inspections should be used to identify any routine maintenance requirements. Nonroutine maintenance practices involve the rehabilitation of the trench after it becomes clogged.

**Routine Maintenance/Inspection.** Infiltration trenches should be inspected several times within the first few months of operation; thereafter, the trenches should be inspected annually. Infiltration trenches should also be inspected after large storm events to check for surface ponding. Surface ponding might indicate the trench is clogged by sediments. Water levels in the observation well should also be monitored over several days to check that the trench has an adequate storage time. If the storage time of an infiltration trench exceeds 3 days, the trench could be clogged.

**Buffer Maintenance.** The filter strips used with surface trenches should be inspected annually. They should be reseeded or resodded wherever eroded areas are observed. Grassed filter strips should be mowed at least twice a year to prevent woody growth as well as for aesthetic reasons. To prevent lawn clippings from clogging the trench, lawn mowers should be equipped with baggers.

**Sediment Removal.** The inlets of underground trenches should be checked periodically and cleaned out when sediment depletes more than 10 percent of the available capacity. Removing sediments from the inlets could be done manually or by a vacuum pump.

**Tree Pruning.** The trees adjacent to any infiltration trench may need to be trimmed if the dripline of the trees extends over the trench. Pruning the trees will also help to prevent the leaves of the tree from

**Table 3**  
**Maximum Infiltration Trench Depths**

Soil Texture	Infiltration Rate (in./h)	Maximum Trench Depth* (in.)
Sand	8.27	489
Loamy sand	2.41	434
Sandy loam	1.02	183
Loam	0.52	93
Silt loam	0.27	49

\*assumes a void ratio of 0.4

clogging the trench. Trees that grow close to a trench should be removed immediately to avoid having the roots puncture the filter fabric which may allow the underlying soils to enter the trench.

**Nonroutine Maintenance.** The primary nonroutine maintenance task involves rehabilitating the trench after it becomes clogged. Clogging in surface trenches is most likely to occur near the top of the trench. Surface clogging can be relieved by carefully removing the top layer of aggregate, and cleaning or replacing it. Clogging of underground trenches is a much more serious problem, as it is likely to occur at the bottom of the trench. Rehabilitation of an underground trench requires removing the layer of topsoil, the geosynthetic membrane, the entire stone aggregate layer, and the bottom filter fabric. After the subsoil layer is tilled to promote better infiltration, each layer of the trench must be replaced.

**Maintenance Costs.** Routine maintenance costs will probably be higher for surface trenches than underground trenches. Surface trench rehabilitation is likely to be approximately 20 percent of the initial construction costs. The cost of rehabilitation of an underground trench will be approximately equal to the initial construction cost. If one assumes that surface and underground trenches will need rehabilitation every 5 to 15 years, the annual maintenance costs will be approximately 5 to 10 percent and 10 to 15 percent of the initial construction cost for surface trenches and underground trenches, respectively. These annual maintenance costs would be required to cover both routine and nonroutine maintenance expenditures.

## **Infiltration Basins**

### *Description*

An infiltration basin is an impoundment that stores a defined quantity of stormwater runoff. The stored runoff slowly infiltrates through the permeable soils of the basin floor. The basin floor is graded as flat as possible and a dense turf of grass is established to promote infiltration and to bind deposited sediments. Additional storage can be provided in the basin to provide temporary detention of the larger stormwater runoff volumes by using a conventional riser. An emergency spillway is used to convey the runoff volumes in excess of the design storm. Some variations in infiltration basin designs include:

1. Full infiltration basin (Figure 23).
2. Combined infiltration/detention basin (Figure 24).

3. Side-by-side basin (Figure 25).

4. Off-line infiltration basin (Figure 26).

Infiltration basins can most closely reproduce natural hydraulic conditions. When properly designed and sized, infiltration basins can completely manage peak discharges, provide groundwater recharge, reduce storm runoff volumes, and protect downstream channels from erosion.

*Target Pollutants*

Infiltration basins are very effective for removing fine sediments and pollutants associated with fine sediments. Coarse sediments are also effectively controlled, but coarse sediments should be removed from stormwater runoff before it enters the basin. Pollutants are removed from stormwater runoff by diverting it into the basin and allowing the runoff to infiltrate through the floor of the basin and into the underlying soils. The underlying soil layer has been shown to be a highly effective and normally safe means of removing stormwater runoff pollutants.<sup>21</sup>

*Effectiveness*

Infiltration basins can be designed to provide total control of urban pollutants in surface runoff for the design runoff volume. As stormwater runoff enters an infiltration basin, many pollutants will be trapped or treated as the runoff infiltrates into the underlying soils. Stormwater runoff that bypasses the infiltration basin will be conveyed downstream untreated. Although infiltration basins are very effective for controlling pollutants in surface water, certain soluble substances can be expected to move into the groundwater. Chloride from road salt is an example of a soluble substance that will be removed during the infiltration process.

*Planning Considerations*

Infiltration basins can be applied to sites with drainage areas of 5 to 50 acres.<sup>22</sup> A typical basin will have a depth of 3 to 12 ft. The maximum depth of the basin will be limited by the infiltration rate of the soil and maximum detention time. Infiltration basins are not feasible for sites with soils that have infiltration rates of less than 0.27 in./hour, or any soil with a clay content greater than 30 percent. A geologic investigation of the specific site will be required for the design of an infiltration basin. The borings and trenches used for the geologic investigation should extend to a depth of at least 5 ft below the bottom of the proposed basin.

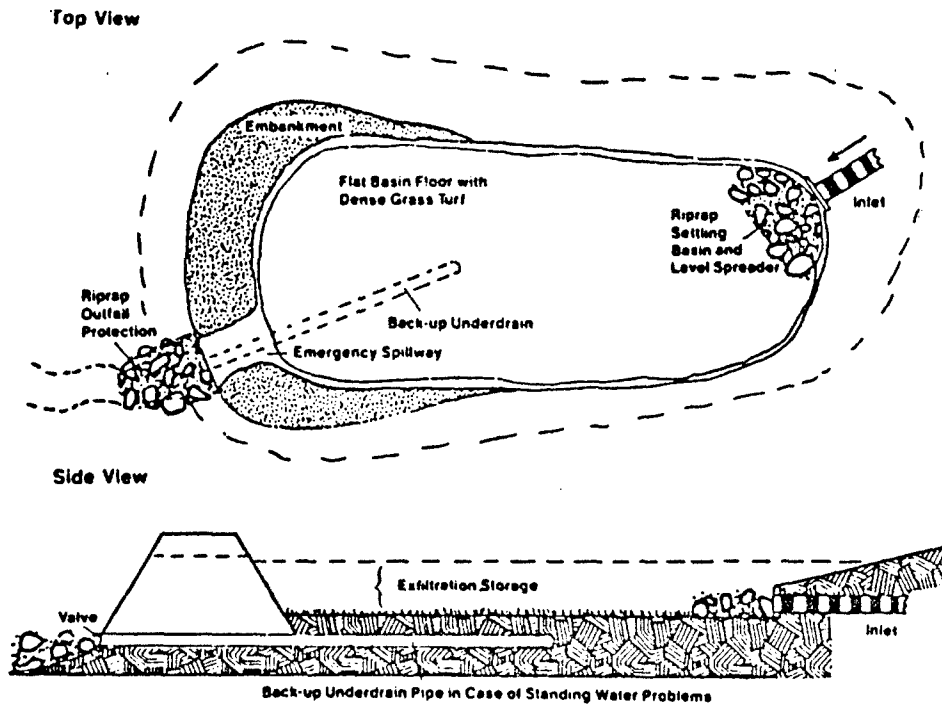
The seasonal high water table should be at a minimum of 2 to 4 ft below the bottom of the basin. This distance allows the stormwater runoff to be treated before it reaches the groundwater table and ensures that water will drain from the basin. Infiltration basins in commercial and industrial areas should be at least 100 ft away from any drinking water wells, and should be located at least 10 ft downgradient and 100 ft upgradient from building foundations. In all cases, infiltration basins must be designed to prevent any potential groundwater contamination.

The threat of groundwater contamination is a primary concern when planning an infiltration basin. The effects of infiltration basins on groundwater has been studied as part of the Nationwide Urban Runoff Program (NURP). The NURP studies concluded that there was no evidence of groundwater contamination from infiltration basins. However, this does not mean groundwater cannot be adversely affected by

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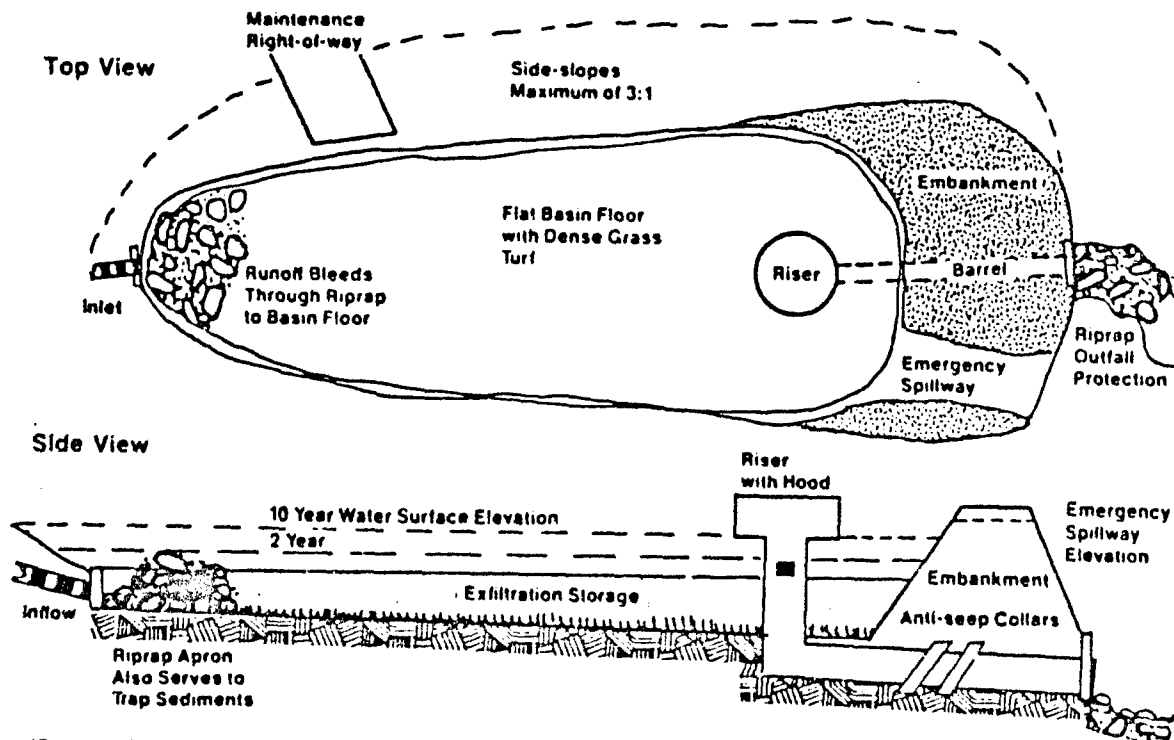
<sup>21</sup> Metropolitan Washington Council of Governments, 1979.

<sup>22</sup> Maryland Water Resources Administration, *The Effects of Alternative Stormwater Management Design Policy on Detention Basins* (Annapolis, MD, 1983).



(Source: Schueler, 1987. Used with permission.)

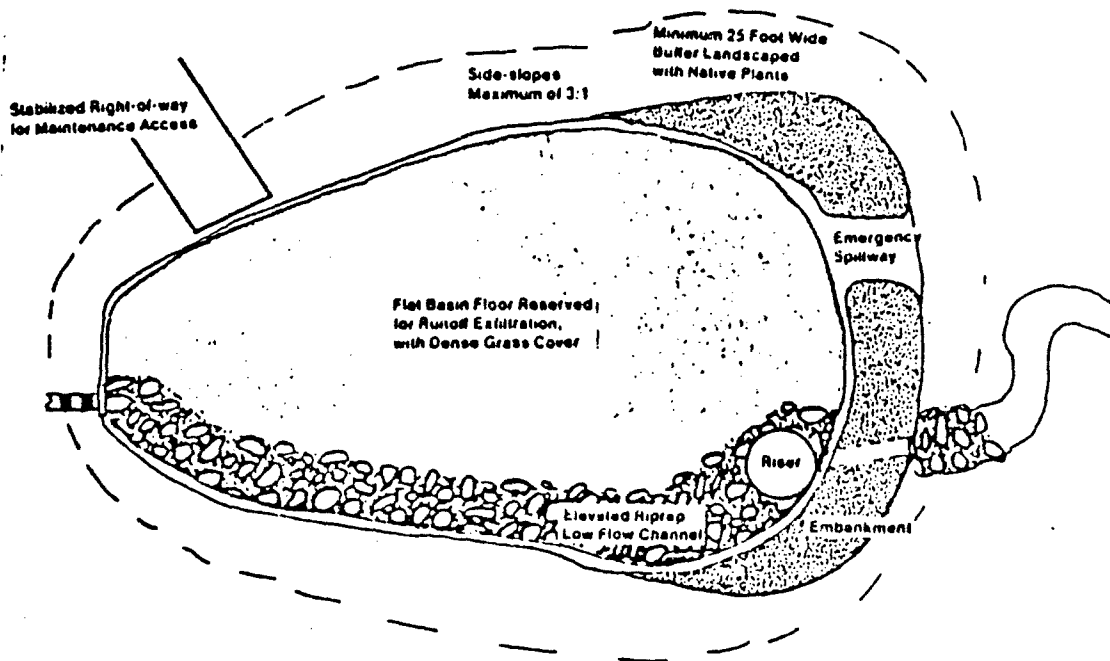
**Figure 23. Schematic of an Infiltration Basin.**



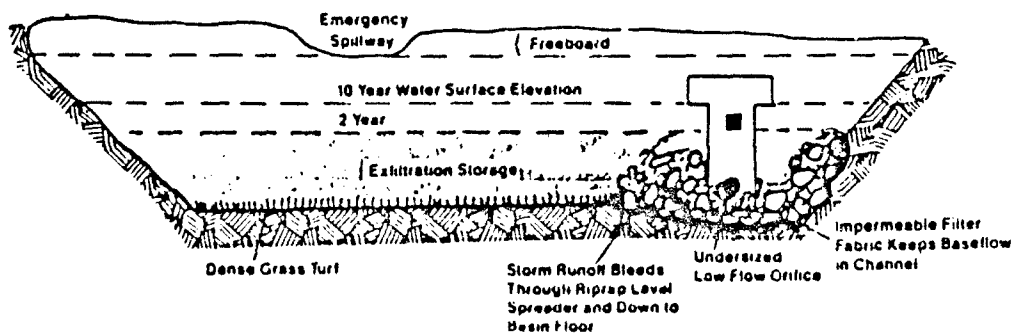
(Source: Schueler, 1987. Used with permission.)

**Figure 24. Schematic of a Combined Infiltration/Detention Basin.**

### Top View



### Cross-sectional View of Embankment



(Source: Schueler, 1987. Used with permission.)

Figure 25. Schematic of a Side-by-side Infiltration Basin.

infiltration basins. Therefore, a site sensitivity analysis is recommended, which would identify any potential effects on groundwater.

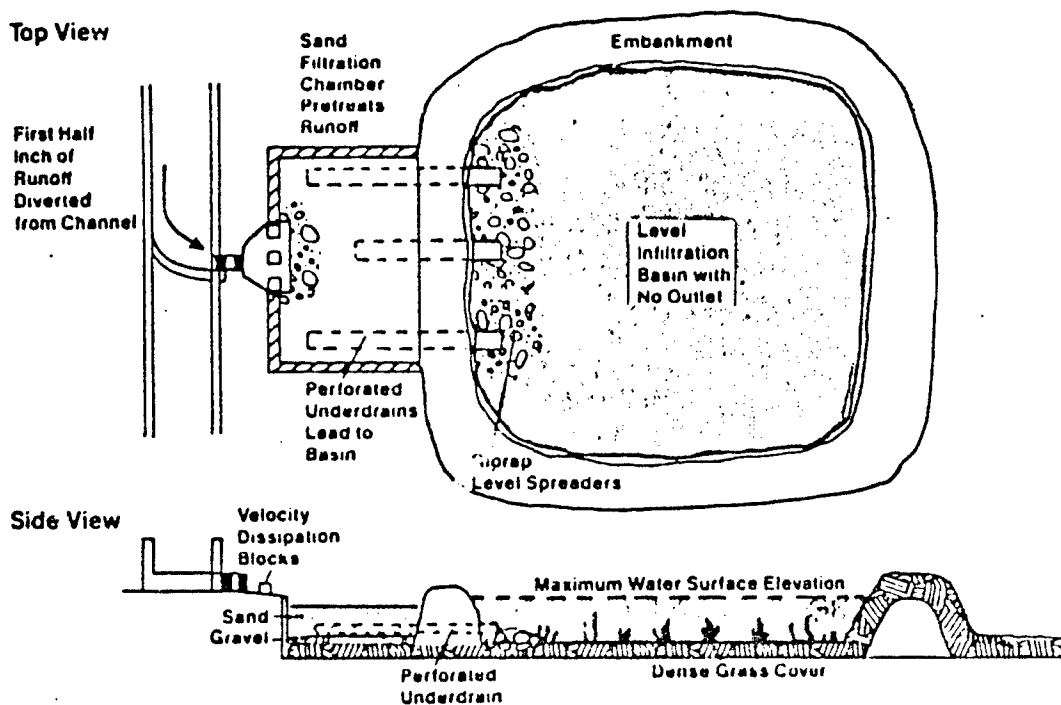
#### *Design Recommendations*

**Tilling.** If heavy equipment is used to grade the floor of the basin, it should be immediately tilled to offset any compaction that has taken place.

**Storage Time.** An infiltration basin should be designed to drain completely within 3 days after a storm event. The combination of storage time, storage volume, and infiltration rate could be used to determine the maximum depth of the basin. Infiltration basins deeper than the maximum depth basins will have storage times greater than the recommended 3 days.

**Sediment Forebays.** An infiltration basin can be enhanced if sediment forebays are constructed near the inlets. The sediment forebays are designed to provide energy dissipation of the incoming water and to trap coarse sediments. Therefore, sediment forebays are important because they reduce sediment loads, reduce incoming water velocity, and distribute the incoming water more uniformly across the floor of the basin.

**Runoff Filtering.** Oil, grease, floating organic matter, and suspended soil should be removed from stormwater runoff before it enters the infiltration basin. Devices such as vegetated filter strips, oil/grease separators, or floatable skimmers could be used to remove these pollutants.



(Source: Schueler, 1987. Used with permission.)

**Figure 26. Schematic of an Off-Line Infiltration Basin.**



**Structural Design.** All embankments, spillways, etc. should be designed and constructed in conformance with the *SCS Field Office Technical Guide*.

**Principal Spillways.** If a combination detention/infiltration basin has been chosen, the elevation of the principal spillway crest should be no higher than the 3-day infiltration capacity of the basin. All other aspects of the basin design such as flood routing should meet the requirements of an extended detention basin. An example of a combination detention/infiltration basin is shown in Figure 24.

**Construction.** Before the site is graded, the area planned for the basin should be roped off to prevent heavy equipment from compacting the underlying soils. If the basin is not designed for sediment control, diversion berms should be placed around the perimeter of the basin during all phases of construction. If the basin is designed for temporary sediment control during adjacent construction, the basin should only be excavated to within 2 ft of the final grade of the basin floor using light earth-moving equipment with tracks or over-sized tires. The basin should be stabilized with vegetation within a week after construction. The basin embankment and inlet/outlet channels should be constructed following local basin specifications, such as core trenches and antiseep collars.

#### *Maintenance*

The maintenance of infiltration basins can be characterized by two distinct categories: routine and nonroutine maintenance practices. Routine maintenance practices include mowing, removal of debris, erosion control, and tilling. Maintenance inspections should be used to identify any routine maintenance requirements. Nonroutine maintenance practices include structural repairs, restoration of infiltration capacity, and sediment removal.

**Routine Maintenance/Inspection.** Infiltration basins should be inspected several times within the first few months of operation; thereafter, the basin should be inspected annually. Some of the more important items to check include: differential settlement, cracking, erosion, leakage, tree growth on the embankment; the condition of the riprap in the inlet, outlet, and plot channels; sediment accumulation in the basin; and the vigor and density of the grass turf on the floor of the basin.

**Mowing.** The buffer, side slopes, and basin floor should be mowed at least twice a year to prevent woody growth. More frequent mowing may be required if the basin is to be used as a recreation area.

**Removal of Debris.** Infiltration basins will tend to collect trash that may clog the outlets of the basin. Therefore, it is a good practice to remove all debris and litter during each mowing operation.

**Erosion Control.** Eroding or barren areas of the basin should be revegetated immediately. This is very important since eroded sediments can adversely affect the infiltration capacity of a basin.

**Tilling.** Annual or semiannual tilling operations may be required to maintain the infiltration capacity of the basin. A rotary tiller or disc harrow can be used, preferably in the late summer months. Tilled areas should be revegetated immediately to prevent erosion.

**Nonroutine Maintenance/Structural Repairs.** Deterioration of the various inlet/outlet structures in an infiltration basin will require repair or replacement. The replacement costs are difficult to estimate, but will most likely constitute a significant future expense.

Water seeping through the embankment could lead to the internal erosion of the embankment, which could create instability within the embankment. To prevent the problems associated with internal erosion, the embankments should be constructed out of well-compacted clayey soils; antiseep collars should be installed around any barrel pipes.

**Restoration of Infiltration Capacity.** Over time, the original infiltration capacity of the basin floor will gradually decrease due to surface clogging. Deep tilling could be used to break up the clogged surface layer, followed by regrading and revegetation of the basin floor. In some circumstances, sand or organic matter can be tilled into the basin soils to increase the infiltration capacity. If a basin still experiences chronic problems with standing water after these measures have been taken, it is likely that the original infiltration capacity was over estimated.

**Sediment removal.** Sediment removal methods in infiltration basins are different from those used for extended detention basins and detention/retention basins. Removal should not begin until the basin has thoroughly dried out. The top layer should then be removed by light equipment. The remaining soil can then be deeply tilled with a rotary tiller or disc harrow to restore infiltration rates. Areas disturbed during sediment removal should be revegetated immediately to prevent erosion.

**Maintenance Costs.** The routine and nonroutine maintenance practices for infiltration basins are similar to the practices associated with conventional dry detention basins. Therefore, it may be assumed that the annual maintenance costs for routine and nonroutine practices will be approximately equal to 3 to 5 percent of a basin's initial construction costs.<sup>23</sup>

## **Natural and Constructed Wetlands**

### *Description*

The treatment of nonpoint source pollution by the use of wetlands involves passing stormwater runoff through either natural or constructed wetland regions. Wetlands provide favorable conditions for removing pollutants in stormwater runoff by the process of sedimentation. Wetlands also provide an environment for intense biological activity, and this biological activity will help to remove dissolved nutrients from the stormwater runoff. The primary problems associated with using wetlands to treat stormwater runoff are the environmental damage that may be done to natural wetlands, and the large spatial requirement for constructed wetlands.

### *Target Pollutants*

Using constructed wetlands or natural wetlands to treat stormwater runoff is very effective in removing suspended solids, such as sediments and trace metals. Wetland treatment is also very effective in removing oxygen demanding substances and bacteria. Dissolved nutrients are effectively removed by biological uptake during the growing season and by being adsorbed onto sediments that will settle out of the runoff. Therefore, the use of wetlands is very effective for removing a broad range of pollutants found in stormwater runoff.

### *Effectiveness*

The effectiveness of a wetland depends primarily on its physical characteristics. Wetlands can be characterized based on the residence time of the runoff in the wetlands, the water budget for the wetlands, and the ratio of the size of the wetlands to the size of the watersheds. In general terms, as the wetland-to-watershed ratio increases, the runoff residence time will also increase and the effectiveness of the wetland to remove pollutants will increase. The effectiveness of wetlands for removing nutrients however, also depends on the seasonal changes of the wetland regions (i.e., nutrient uptake will be greatest during the seasons when biologic activities are maximized).

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<sup>23</sup> C. Wiegand, et al., 1986.

### *Planning Considerations*

Although wetlands can be very effective for treating stormwater runoff, the runoff could overload a natural wetland region, which will eventually lead to the degradation of the natural wetland. The suspended solids removed from stormwater runoff will be deposited in the wetlands, and the deposition of suspended solids may make the removal process at a future time very difficult. Therefore, steps should be taken to minimize the degradation of natural wetlands.

The accumulation of trace metals associated with stormwater runoff will occur in both natural and constructed wetlands. Studies have been performed to determine the levels of trace metals in plant tissue, sediments, and fish tissue from wetlands used to treat stormwater runoff.<sup>24</sup> The results of these studies found that high levels of trace metals exist in the sediment and that bioaccumulation of the trace metals occurs in fish. The effects of trace metals on waterfowl has not been determined.

The bioaccumulation of trace metals makes it desirable to keep wildlife away from wetlands used to treat stormwater runoff. The effects of bioaccumulation and the potential damage to wetlands from accelerated sedimentation indicate that natural wetlands should not be used as primary treatment for stormwater runoff. However, natural wetlands could be used as a secondary treatment process after the stormwater runoff has been treated by another BMP such as a detention basin. Natural wetlands could provide some additional removal of fine suspended solids and could provide for the removal of some nutrients by the process of biological uptake.

The primary problem associated with using wetlands to treat stormwater runoff is that any proposed construction located near natural wetlands may be subject to state and/or Federal regulations. Therefore, it is necessary to contact the state office responsible for regulatory control of wetlands to get information on state regulations and permits related to wetlands. Contact the U.S. Army Corps of Engineers Regulatory Branch for information on Federal regulations and permits related to wetlands.

### *Design Recommendations*

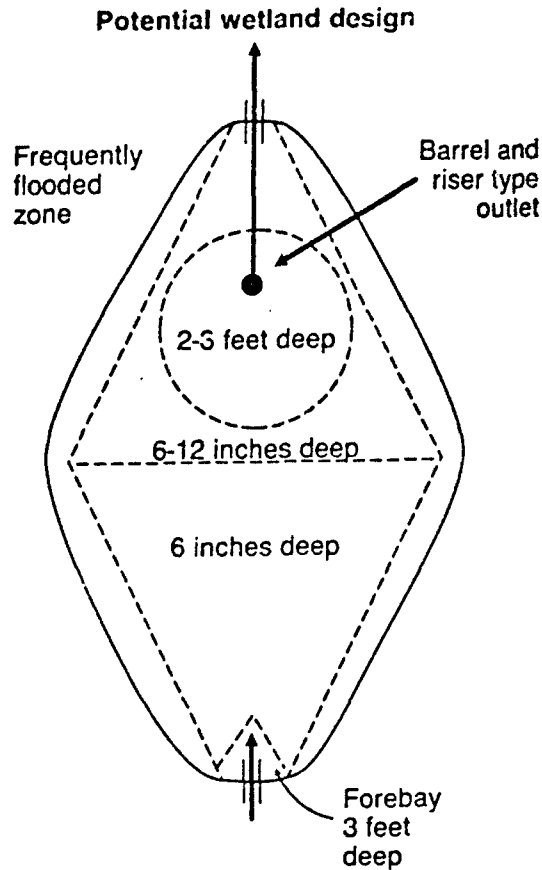
**Wetland Size.** The Maryland Department of Natural Resources has developed guidelines for constructing wetland stormwater basins.<sup>25</sup> Those guidelines recommend that the wetland surface area be equal to 3 percent of the total watershed area, unless extended detention is used with the outlet design. If extended detention is not used with the outlet design and the wetland area criteria cannot be achieved, a different BMP, such as a detention basin, should be used in place of the constructed wetlands.

**Wetland Configuration.** It is recommended that no more than 25 percent of the wetland area be open water. The remaining area should be heavily vegetated. The area of open water and vegetation can be controlled by the depth of the water in the wetland. Water deeper than 2 ft will generally result in open water while shallow areas will tend to be vegetated. Figure 27 shows a possible layout of a constructed wetland area as recommended by the Maryland guidelines. The general features recommended for the wetland design include:

1. Approximately 25 percent of the wetland should be 2 to 3 ft deep.
2. Approximately 75 percent of the wetland should be less than 12 in. deep.
3. The outlet should be located within the deeper portion of the wetland.

<sup>24</sup> U.S. Fish and Wildlife Service (USFWS), results of unpublished sampling data from Long Meadow Lake (USFWS, St. Paul, MN, 1988); E.C. Meiorin. *Urban Stormwater Treatment at Coyote Hills Marsh* (Association of Bay Area Governments, Oakland, CA, December 1986).

<sup>25</sup> *Guidelines for Constructing Wetland Stormwater Basins* (Maryland Department of Natural Resources, Annapolis, MD, 1987).



**Figure 27. A Typical Layout of a Constructed Wetland.**

4. A forebay should be included at the inlet to the wetland. The forebay should be 3 ft deep and should be at least 10 percent of the wetland area.
5. The wetland perimeter should have a border 10 to 20 ft wide that will be temporarily flooded during most storm events.
6. The inlet to the wetland should be located in the shallow portion of the wetland.

**Soil Conditions.** Soils at the proposed wetland site should have an infiltration rate low enough so that base flow or stormwater runoff can maintain a permanent pool. Where possible, soils that resemble natural wetland soils should be used to construct the bottom of the proposed wetland. Natural wetland soils usually contain hydrophytic plant propagules, which can be expected to grow in the new wetland. If natural wetland soils are not available, most other soils will allow wetland vegetation to establish itself as long as there is a sufficient depth of the soil cover. A minimum soil depth of 4 in. is recommended for the design of a constructed wetland.

**Vegetation.** The preferred method of vegetating a constructed wetland is by spreading wetland soils in the pool area. These soils will generally contain a large number of wetland plant propagules that can be expected to establish vegetation in a constructed wetland. If natural wetland soils are not available,

wetland vegetation may need to be established by transplanting stocks gathered from local wetlands or purchased from suppliers.

### *Maintenance*

Sediment accumulation will be the primary maintenance concern in shallow wetland sites. Sediment accumulation could result in a loss of ponding area in the wetland. Sediment accumulation could also create channels that can short-circuit the wetland. The elevation of the permanent pool can be raised as the wetland fills in until the temporary storage volume is reduced to the minimum criteria that is acceptable according to the design requirements of the wetland. When the temporary storage volume reaches the minimum criteria, the wetland should be dewatered and the sediment should be removed. Therefore, the maintenance cycle of wetlands used to treat stormwater runoff will be dictated by the rate of sedimentation and volume of sediment entering the wetland sites.

### *Porous Pavement*

#### *Description*

A typical cross-section of porous pavement is shown in Figure 28. Stormwater runoff rapidly infiltrates through the pores of the 2- to 4-in. porous asphalt layer into the void space of an underground reservoir. The runoff then exfiltrates out of the stone reservoir and into the underlying subsoils, or the runoff is collected by perforated underdrain pipes and routed to an outflow structure. Under normal conditions, the porous asphalt layer merely acts as a rapid conduit for runoff to reach the stone reservoir. A less preferable alternative for directing runoff into the stone reservoir would be to install drop inlets through the porous asphalt layer. The primary problem associated with using porous pavement is that the system will easily clog if sediment is not kept off of the pavement.

#### *Target Pollutants*

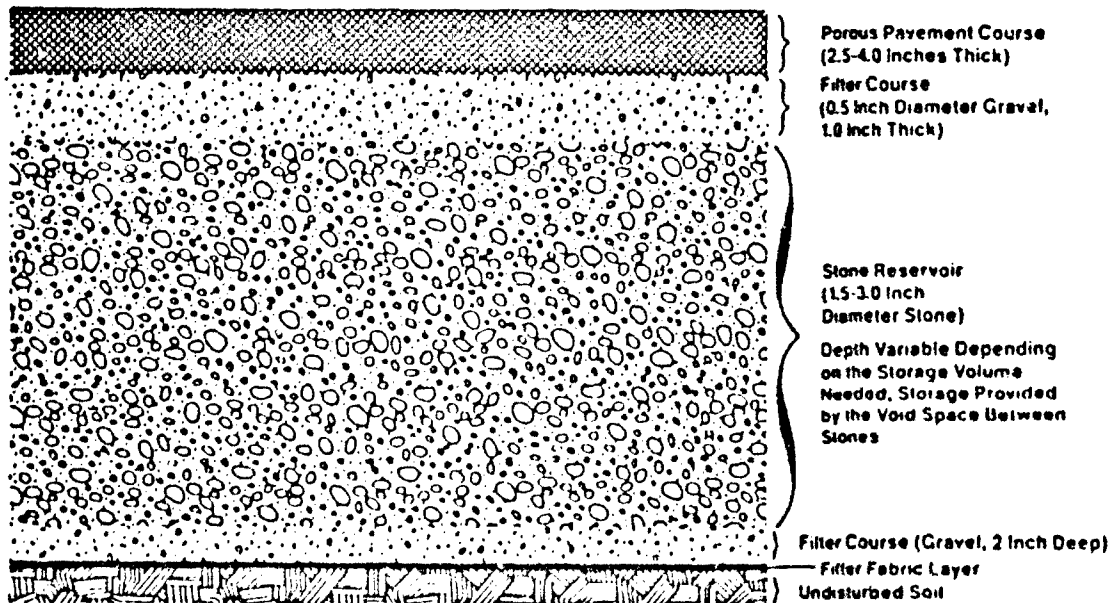
Porous pavement has the capability of removing both fine particulate pollutants and soluble nutrients that exist in stormwater runoff. Most of the pollutant removal in a porous pavement site is accomplished after the stormwater runoff infiltrates into the underlying soils. Therefore, the degree of pollutant removal in porous pavements is directly related to the amount of runoff that is actually infiltrated into the soil. The pollutant removal mechanisms for porous pavement are similar to the mechanisms associated with infiltration trenches.

#### *Effectiveness*

Porous pavement is very effective in removing both soluble nutrients and fine particulate pollutants from stormwater runoff. Porous pavement can also be used to provide groundwater recharge, low flow augmentation, and streambank erosion control. Porous pavement is generally restricted to low volume parking areas, although it can accept runoff from rooftop storage or adjacent paved areas. Porous pavement will be feasible only on sites with gentle slopes, permeable soil conditions, and relatively deep water table and bedrock levels.

When properly designed and constructed, porous pavement will have good load bearing capacity and longevity. Maintenance requirements are similar to conventional pavement sections. The advantages to using porous pavement include reduced land consumption, reduction of required curbs and gutters, the preservation of the natural stormwater flow conditions, and a safer driving surface which offers better skid resistance and reduced hydroplaning. The primary disadvantage to using porous pavement is the potential for clogging, which is fairly high. If the porous pavement becomes clogged, rehabilitation would be very difficult and costly. Therefore, the pavement should be designed to minimize the potential risk of clogging.

### Side View



(Source: Schueler, 1987. Used with permission.)

**Figure 28. A Typical Porous Pavement Section.**

### *Planning Considerations*

Porous pavement is most applicable on sites with relatively small drainage areas and can be used to control runoff from parking lots and rooftops. The use of porous pavement should be restricted to sites with gentle slopes, fairly permeable soil conditions, and relatively deep water table and bedrock levels. Therefore, proposed sites should be evaluated based on these factors.

Soil permeability is a major consideration in determining if porous pavement is feasible at a given site. Soils with an infiltration rate of 0.27 in./hour or greater will be the most suitable. The seasonal high water table should be at least 2 ft below the bottom of the stone reservoir. This will allow for treatment of the stormwater runoff before it reaches the groundwater table, and will ensure that water will drain from the stone reservoir. The depth to bedrock should also be at least 2 ft below the bottom of the stone reservoir. The information required to determine the depth to bedrock and the seasonal high water table could be obtained from local soil maps or by taking several solid borings.

Porous pavement is not recommended on sites with slopes that exceed 5 percent. If the slopes of a given site exceed that level, the stormwater runoff will have velocities that are not acceptable for infiltration. The velocity of the stormwater must be slow enough so the runoff will infiltrate through the layer of porous pavement. Porous pavements should also be located at least 100 ft away from any drinking water wells to minimize the possibility of groundwater contamination. Porous pavement should also be situated at least 10 ft downgradient and 100 ft upgradient of any building foundations.

Porous pavement is generally only used for parking lots and lightly used access roads. If a portion of the parking lot is expected to receive moderate to heavy traffic use, that area could be conventionally paved and sloped to drain towards the porous pavement.

Lastly, porous pavements should not be used at locations that will be receiving sediment loads that could clog the system. In most cases, a vegetative filter or some other means of removing coarse sediments should be used to treat the stormwater runoff before it reaches the porous pavement.

### *Design Recommendations*

**Storage Volume.** The pollutant removal performance of porous pavements depends on how much of the annual runoff is exfiltrated into the underlying soils. Stormwater runoff that is not exfiltrated will receive very little pollutant removal treatment. Therefore, porous pavement applications should be designed to exfiltrate a minimum of runoff volume equivalent to the first 0.5 in. of runoff from contributing impervious areas.

The aggregate used for the stone reservoir should be clean, washed rock with a minimum diameter of 1.5 in. and a maximum diameter of 3 in. For this size-of aggregate, a void ratio of 30 to 40 percent can be assumed. The void ratio is equal to the ratio of the volume of void space to the total volume of the stone reservoir. Therefore, the storage volume available is a product of the stone reservoir volume and the void ratio.

**Storage Time.** The maximum storage time should be at least 72 hours. This storage time along with the void ratio of the stone aggregate and the infiltration rate of the subsoil can be related to determine the maximum reservoir depth that can be used. Stone reservoirs deeper than the maximum depth would take longer than 72 hours to completely drain.

Moderate to poor pollutant removal has been reported for exfiltration systems that hold water less than 6 hours.<sup>26</sup> As a general design rule, a minimum residence time of 12 hours should be used for a given design storm.

**Construction.** Proper construction of a porous pavement system is extremely important. If installed properly, porous pavement should last as long as convention pavement. However, a substantial number of recent projects have failed shortly after being built, primarily due to poor construction practices, inadequate field testing, or lack of sediment control; porous pavement requires a high level of construction expertise and workmanship.

**Runoff Filtering.** If the porous pavement site receives runoff from offsite areas, a pretreatment facility should be constructed to remove oil, grease, floating organic matter, and sediments before they can enter the stone reservoir. The pretreatment facility would be used to help minimize the potential risk of clogging the porous asphalt or stone reservoir. Sand filters, water quality inlets, short trenches, or barrel inlets could be designed to filter the stormwater runoff from offsite areas.

### *Maintenance*

The surface of porous pavement must be cleaned regularly to prevent clogging by fine sediments. Cleaning will be best accomplished by using a vacuum cleaning street sweeper. Outside of regular cleaning, porous pavement requires no more maintenance than conventional pavement. Application of abrasive material in times of heavy snowfall must be closely monitored to avoid clogging problems. No method of maintenance has been satisfactory on fully clogged pavements.

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<sup>26</sup> Metropolitan Washington Council of Governments, *Urban Runoff in the Washington Metropolitan Area* (USEPA and Water Resources Planning Board, 1983).

The oils in the asphalt tend to bind dirt, and only an abrading and washing technique can effectively remove the dirt. Clogging to a depth of 0.5 in. is sufficient to prevent water penetration. For clogged pavements, drilling one 0.25-in. hole per square foot of pavement is recommended to restore the original drainage capacity. An observation well should be installed on the downslope end of the porous pavement area to monitor drainage time of the stone reservoir.

## **Water Quality Inlets**

### *Description*

Water quality inlets are chambers designed to remove sediment and hydrocarbons from stormwater runoff. Water quality inlets are used close to the source of contamination before pollutants are discharged into a storm drainage network or to an infiltration BMP. The inlets are typically used in areas with heavy traffic or high potential for petroleum spills such as parking lots, gas stations roadways, and loading zones.

### *Target Pollutants*

Water quality inlets are intended to remove moderate amounts of coarse sediment, oil/grease, and floatable debris. The removal of fine-grained particulate pollutants such as silt, clay, and trace metals is expected to be fairly limited. The inlets are not effective for removing soluble pollutants.

### *Effectiveness*

Stormwater runoff is only briefly retained in water quality inlets, so only moderate pollutant removal rates can be expected. Inlets are generally designed to store a small portion of the 1- or 2-year design storm. Therefore, the inlets typically serve parking lots 1 acre or less in size, and are most appropriate for sites that are expected to receive a large volume of vehicular traffic or hydrocarbon inputs such as gas stations, roadways, and loading zones. The advantages of water quality inlets lie in their unobtrusiveness, compatibility with storm drainage networks, easy access, and capability to pretreat stormwater runoff before it enters an infiltration BMP. The disadvantages of water quality inlets include their moderate stormwater and pollutant removal capabilities, the need for frequent maintenance, and possible difficulties in disposing of accumulated sediments.

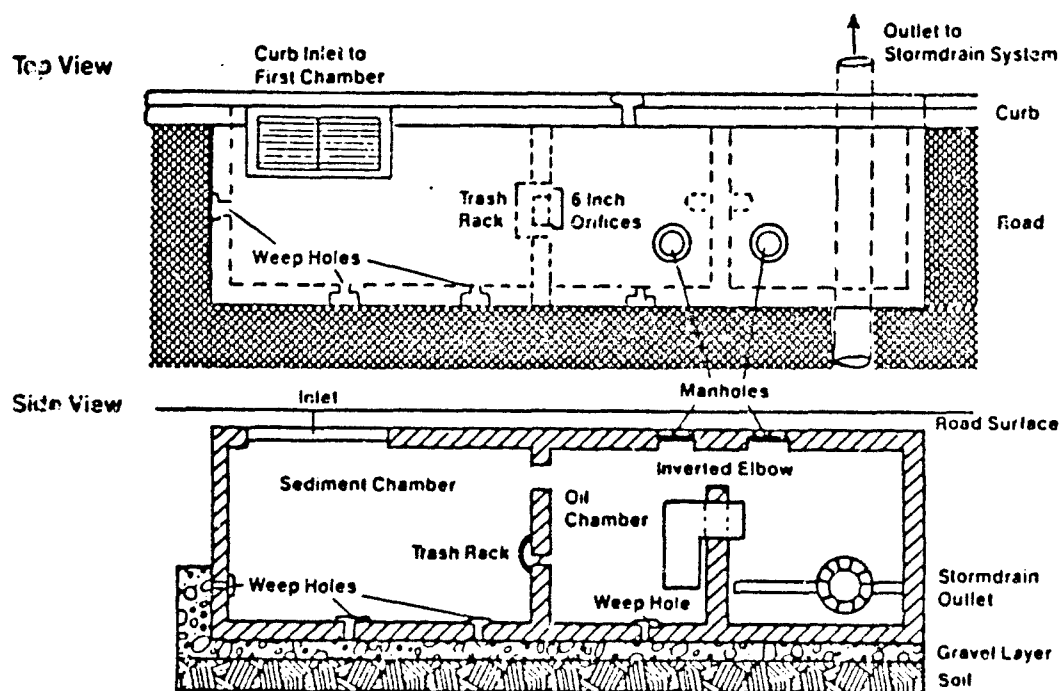
### *Design Considerations*

A typical three-chamber water quality inlet design is presented in Figure 29. Basically, the inlet is a long rectangular concrete chamber that is connected to a storm drainage network. Stormwater runoff enters the first chamber, which contains a permanent pool of water 3 to 4 ft deep. The first chamber will trap coarse sediments by allowing settling. The first chamber can also trap floating debris such as leaves and litter.

Stormwater runoff then passes through an orifice into a second chamber that also contains a permanent pool of water. An inverted pipe elbow, which takes water from the lower portion of the pool, discharges to a third chamber. By drawing water from below the water surface, floating hydrocarbons are trapped until they are absorbed to soil particulates which then settle out.

The third chamber discharges to a storm drain or other outlet. If the storm drain invert is above the floor of the chamber, a permanent pool of water will be formed, which will allow for some additional sedimentation. If the storm drain invert is at the floor of the chamber, the third chamber would have no effective value in pollutant removal.





(Source: Schueler, 1987. Used with permission.)

**Figure 29. Schematic of a Water Quality Inlet.**

Water quality inlets should be designed to provide at least 400 cu ft of permanent pool storage per acre of drainage area, and the permanent pool should be at least 4 ft deep.<sup>27</sup> Additional dry storage should also be provided to convey the design storm. Access to each chamber for inspection and regular cleanouts should be provided by separate manholes.

#### *Maintenance*

Water quality inlets must be cleaned out at least twice a year to maintain their pollutant removal capabilities. The normal method used to clean out the inlets is to pump out the contents of each chamber. An alternative disposal is to carefully siphon out each chamber and allow the contents to infiltrate over a nearby grassed area. Failure to clean out water quality inlets regularly could result in resuspension and loss of previously trapped pollutants.

#### **Floatable Skimmers**

##### *Description*

Floatable skimmers are devices used to retain floating debris and hydrocarbons in detention areas so they eventually settle to the bottom of the detention area and become part of the sediments. Floatable skimmers are typically used with the outlet structures of detention/infiltration basins.

<sup>27</sup> Montgomery County Department of Environmental Protection, *Oil-Grit Separator Design Checklist* (Rockville, MD, 1984).

### *Target Pollutants*

Floatable skimmers are effective for trapping and removing floating organic matter and petroleum products, which contain appreciable amounts of nutrients, oxygen demanding substances, and hydrocarbons. Therefore, floatable skimmers could be an effective means of providing pretreatment of stormwater runoff before it enters the control structures.

### *Effectiveness*

The effect of floatable skimmers on water quality will depend on the quantity and type of floating material transported by stormwater runoff. Typically, a well designed floatable skimmer could trap virtually all floating debris that reaches it. In areas with large concentrations of floating leaves, trash, or petroleum hydrocarbons, a skimmer could significantly improve water quality. In general, floatable skimmers will provide an additional amount of stormwater runoff treatment, and their use with preexisting water quality BMPs, such as detention basins, will enhance the pollutant removal capacity of the preexisting BMPs.

### *Design Recommendations*

Floatable skimmers are easily adapted to vertical outlet structures. Figure 30 presents a typical installation of a floatable skimmer for a corrugated metal riser pipe inlet. A floatable skimmer used in this manner could also double as an effective trash rack for the outlet structure.

For structures with a weir outlet, a baffle weir should be designed and constructed. Figure 31 presents a typical installation of a baffle weir. A baffle weir should be located far enough upstream of the outlet structure to prevent high velocity flow conditions through the baffle weir. For the best performance, the flow area through the baffle weir should be sufficient to keep the water velocities around the baffle to less than 1 ft per second.

### *Maintenance*

Maintenance is very important for the proper function of floatable skimmers. After storm events that transport heavy loads of floatable debris, the skimmers could become clogged with a mat of trapped material. The debris should be removed promptly from the skimmers to maintain the capacity of the structure for future storms.

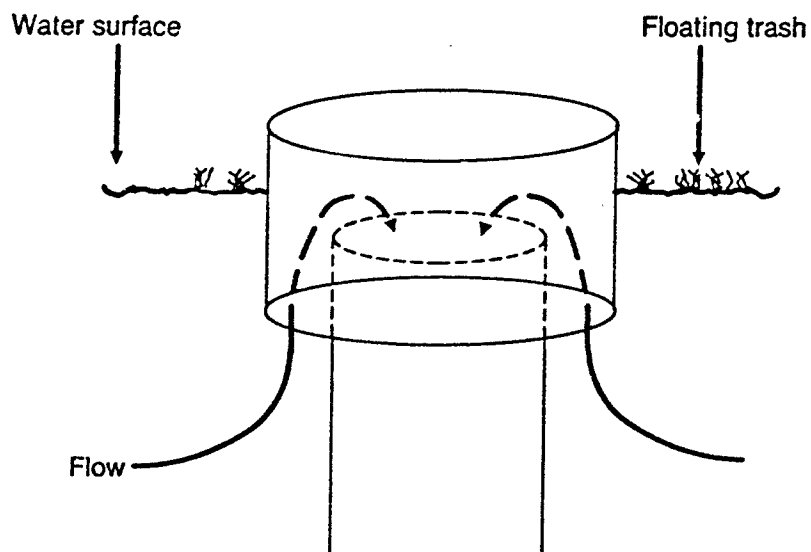
## **Vegetated Swales**

### *Description*

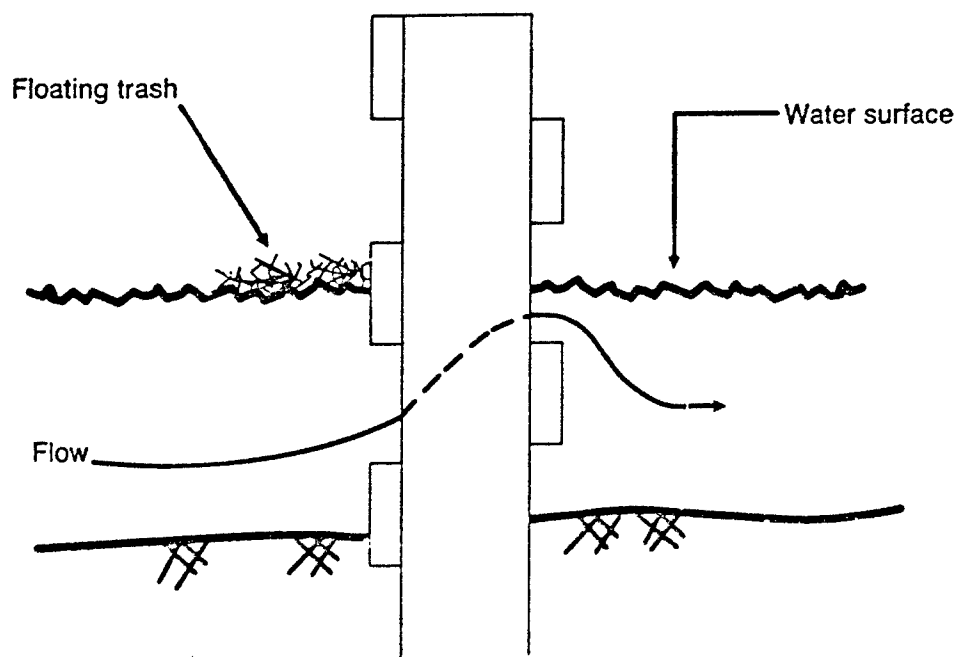
Vegetated swales, broad shallow channels containing a dense growth of vegetation, are designed to promote infiltration and trap stormwater pollutants. The combination of low water velocities and a vegetative cover provide the opportunity for stormwater pollutants to settle out or to be treated by infiltration. Vegetated swales should be used in combination with other BMPs downstream to meet stormwater quality requirements. A typical vegetated swale is presented in Figure 32.

### *Target Pollutants*

Vegetated swales are most effective for removing coarse sediments and the pollutants associated with them. Vegetated swales are not effective in removing fine-grained sediments and soluble pollutants



**Figure 30. A Typical Pipe Inlet Skimmer.**



**Figure 31. A Typical Baffle Weir.**

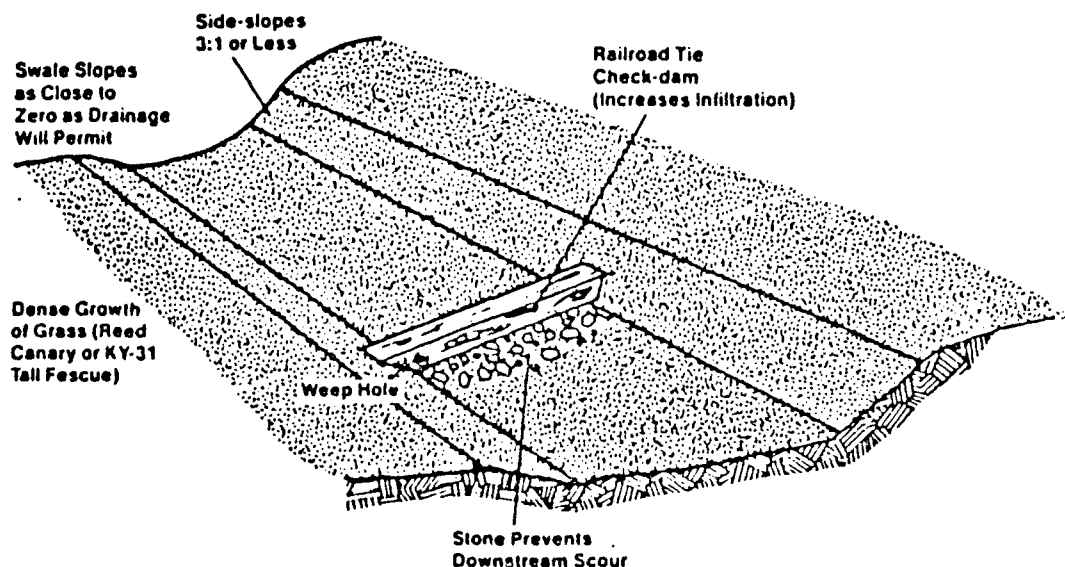


Figure 32. Schematic of a Vegetated Swale.

unless the pollutants are part of the stormwater runoff that infiltrates into the underlying soils. Check dams can be installed in vegetated swales to promote additional infiltration, which will help to raise the pollution removal rates.

#### *Effectiveness*

Vegetated swales are typically used in single-family residential developments and highway medians as an alternative to curb and gutter drainage networks. Vegetated swales have a limited capacity to accept runoff from large storms and usually must lead into storm drainage inlets to prevent erosion due to concentrated flows. Vegetated swales are very effective for removing coarse grained particulates, and are ineffective for removing fine-grained sediments and soluble pollutants. They should be designed in combination with downstream BMPs to meet stormwater quality requirements.

#### *Planning Considerations*

The following characteristics of vegetated swales should be considered when planning a drainage system for a development:

1. Vegetated swales are generally less expensive to install than curbs and gutters.
2. Roadside swales keep flow away from the street surface during storm events.
3. Roadside swales become less feasible as the number of driveways requiring culverts increase.
4. In areas with steep slopes, vegetated swales are best suited to locations where they parallel the topographic contours.

Vegetated swales are most effective when the flow is shallow and the velocity is relatively low. These characteristics tend to limit the use of vegetated swales to locations where flows are less than 5 to

10 cfs. The soil conditions in swales should allow vigorous vegetative growth, and should promote effective infiltration through the bottom of the swales. In addition to the characteristics presented here, the seasonal high water table should be 1 to 2 ft below the bottom of the vegetated swale to allow for the treatment of most pollutants before the runoff reaches the groundwater table.

#### *Design Recommendations*

The vegetated swale channel should be designed for a maximum velocity of 2 ft per second. The depth of flow should also be limited to a maximum of 1 ft to increase the amount of pollutant removal. The combination of these two design requirements will generally result in wide, shallow, vegetated swales.

The grade of the vegetated swale channel should be as flat as possible and should not exceed 2 to 5 percent. Check dams can be installed in vegetated swales to promote additional infiltration. The check dam should be constructed of durable construction materials. Earthen check dams are not recommended because they tend to erode on the downstream side of the dam, and the erosion of the earthen dam would increase the quantity of suspended sediments in the stormwater runoff. The area just downstream of a check dam should also be protected from erosion with a properly designed channel lining system. If check dams are used to enhance the infiltration characteristics of the channel, the check dams should be designed so that the maximum ponding time of runoff behind the dams is less than 24 hours.

#### *Maintenance*

Vegetated swales should be maintained to keep the grass cover dense and vigorous. The grass should be mowed occasionally, but it should not be mowed close to the ground. If the grass is cut close to the ground surface, both the filtering characteristics and the pollutant removal rate will be reduced. The major maintenance operations include weed control, mowing, and occasional fertilization. Fertilization should be done only when needed to maintain the health of the grass. Overapplication of fertilizer could result in the swale being a potential source of nutrients in runoff.

### **Filter Strips**

#### *Description*

Filter strips are similar to vegetated swales but they are designed to accept overland sheet flow only. The grass or close-growing vegetation slows down the stormwater runoff and allows the pollutants to settle out. A typical example of the application of filter strips is presented in Figure 33.

#### *Target Pollutants*

The pollutant removal mechanisms in filter strips are similar to the mechanism associated with vegetated swales. Filter strips can be used to trap solids such as sediment, trash, trace metals, and organic matter from runoff. They also can be effective for soluble pollutant removal, but only to the extent that runoff infiltrates into the subsoils.

#### *Effectiveness*

The pollutant removal rates of filter strips are a function of the length, the slope, and the permeability of the filter strip, the size of the drainage area, the velocity of the stormwater runoff, and the type and density of the vegetative cover. If the stormwater is allowed to concentrate because of poor grading or uneven runoff distribution, the filter strip will be short circuited, and will have only minimal

benefits. Filter strips will not function as intended on slopes greater than 15 percent. Steeper slopes should be vegetated but offsite runoff should be diverted around the filter strip. Filter strip performance is best on slopes with grades of 5 percent or less.

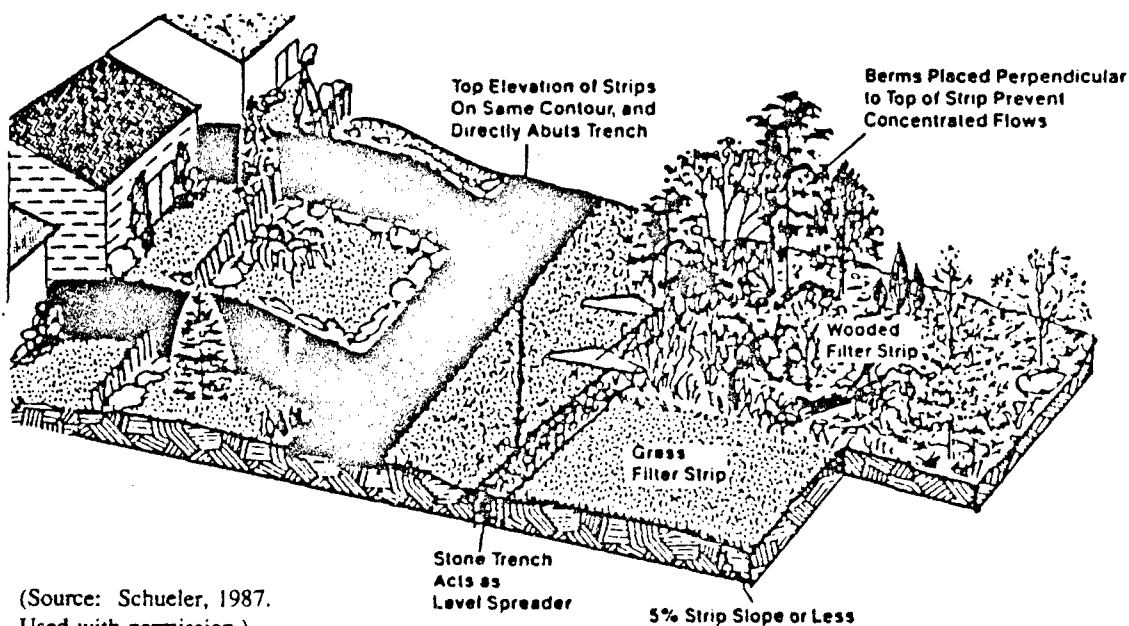
#### *Design Recommendations*

The top edge of the filter strip should follow the same elevation contour. Any change in elevation along the top edge of the filter strip may eventually form a concentrated channel towards the low point. A shallow stone trench could be used as a level spreader at the top of the filter strip to evenly distribute the contributed flow. The top edge of the filter strip should be directly adjacent to the contributing impervious area because the runoff may travel along the top of the filter strip, rather than through the filter strip.

The appropriate length for a strip is still the subject of debate. As an absolute minimum, it should be at least 20 ft long. Even this minimum length will provide some pollutant removal and decrease the runoff volume for small storm events. Better performance could be achieved if the filter strip is 50 to 75 ft long with an additional 4 ft for each 1 percent of slope at the site.<sup>28</sup> Wooded filter strips are generally preferred to grassed filter strips.

#### *Maintenance*

The maintenance requirements of a filter strip depend on whether or not natural vegetative succession is allowed to proceed. Under most conditions, the gradual transformation from grass to forest will enhance rather than degrade the performance of filter strips. If the filter strips are managed as grassed filter strips, they should be mowed regularly and fertilized as required to maintain a healthy vegetated cover. The filter strips should be inspected annually. Based on the results of the annual inspection, any damaged areas should be repaired promptly to prevent erosion. Additional maintenance may be required during the initial period when the vegetative cover is being established.



(Source: Schueler, 1987.  
Used with permission.)

Figure 33. Schematic of a Filter Strip.

<sup>28</sup> T.R. Schueler.

## 7 INDUSTRIAL STORMWATER MANAGEMENT BMPs

Current regulations addressing industrial stormwater require individual installations to develop a stormwater pollution prevention plan. A tremendous variety and number of best management practices are available and appropriate for the control and mitigation of stormwater runoff from such sites as motor pools, wash racks, fueling areas, hazardous materials handling sites, etc. The USEPA has recently published guidance on some potential BMPS for these activities.<sup>29</sup> This guidance includes the following categories: fueling station maintenance and repair, painting operations, washing, loading and unloading materials; liquid storage in above-ground tanks; industrial waste management and outside manufacturing; outside storage of raw materials, byproducts, or finished products, and salt storage. The guidance also presents site specific BMPs grouped in six categories: flow diversion practices; exposure minimization practices; mitigative practices; other preventive practices; sediment and erosion prevention practices; and infiltration practices.

### Activity-Specific Source Control BMPs

#### *Fueling Station BMPs*

- Install spill and overfill protection. Use overfill prevention equipment.
- Discourage topping off of fuel tanks by training employees and posting signs.
- Reduce exposure of the fuel area to stormwater. Build a roof over the fuel area. Pave the fuel area with concrete instead of asphalt. Minimize runoff by using grading, berming, or curbing. Locate roof downspouts to direct stormwater away from fueling areas. Use valley gutters.
- Use oil/water separators and oil and grease traps.
- Use dry cleanup methods for the fuel area rather than cleaning the area with running water.
- Use proper petroleum spill control. Use sorbents for small spills. Avoid washing spills down the drain.
- Encourage employee participation. Properly train employees about ways to eliminate or reduce stormwater contamination.

#### *Maintenance and Repair BMPs*

Vehicle and equipment maintenance and repair uses materials and creates wastes harmful to humans and the environment. A variety of contaminants such as solvents, degreasing products, waste fluids, oils and greases, acids and others may be present.

- Check for leaking oil and fluids. Use drip pans. Use a special area to drain and replace fluids.
- Clean without use of liquid cleaners when possible.

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<sup>29</sup> USEPA, *Storm Water Management for Construction Activities*, EPA 832-R-92-005 (USEPA, September 1992); USEPA, *Storm Water Management for Industrial Activities*, EPA 832-R-92-006 (USEPA, September 1992).

- Use a centralized cleaning station for parts.
- Locate drip pans, drain boards, and drying racks to direct drips back into a sink or fluid holding tank for reuse.
- Use nontoxic or low-toxicity materials. Eliminate or reduce the number or amount of hazardous materials and wastes by substituting nonhazardous or less hazardous materials.
- Drain oil filters before disposal or recycling.
- Don't pour liquid waste down drains.
- Recycle engine fluids and batteries.
- Store cracked batteries in a nonleaking secondary container.
- Segregate and label wastes.
- Buy recycled products.
- Consider roofing over vehicles awaiting salvage or repairs.
- Get employees involved.

#### *Painting Operation BMPs*

Vehicle and equipment painting activities may use materials or create wastes harmful to the environment. Stormwater runoff from areas where these activities occur can become contaminated by a variety of contaminants such as cadmium and mercury.

- Inspect parts before painting. This can mean a better, longer-lasting paint job.
- Use tarps or plastic sheeting to contain sanding wastes. Avoid sanding in windy situations.
- Use tarps, vacuums, drip pans, etc. to prevent paint waste from contacting stormwater.
- Use proper interim storage methods for waste paint, solvents, etc.
- Evaluate efficiency of equipment. Minimize overspray. Consider electrostatic spray equipment, air-atomized spray guns, high-volume/low-pressure spray guns, and gravity-feed guns.
- Recycle paint, paint thinner, and solvents.
- Segregate wastes.
- Buy recycled products.
- Train employees to use equipment properly.



### *Vehicle and Equipment Washing BMPs*

Washing vehicles and equipment outdoors or where wash water flows on the ground can pollute stormwater. Oil and grease, phosphates, metals, suspended solids, and other pollutants are potential concerns.

- Consider use of phosphate-free detergents.
- Use designated cleaning areas.
- Consider recycling wash water.

### *Loading/Unloading Operations BMPs*

Loading and unloading operations usually take place outside on docks or terminals. Materials spilled, leaked, or lost during transfer may be carried away by stormwater runoff.

- Contain leaks during transfer. Equipment and vehicles should be located so leaks can be contained.
- Check equipment regularly for leaks.
- Limit exposure of material to rainfall. Use building overhangs.
- Prevent stormwater runoff by using grading, berming, or curbing to direct stormwater away from the area. Position down spouts away from loading sites.

### *Above-ground Tank BMPs*

Accidental releases of chemicals from above-ground liquid storage tanks can contaminate stormwater with many different pollutants.

- Comply with applicable state and Federal laws requiring SPCC plans, secondary containment, and other specific standards.
- Properly train employees.
- Install safeguards against accidental releases. Use overflow protection devices or protective guards, and clearly tag and label valves.
- Routinely inspect tanks and equipment using both visual inspection and integrity testing.
- Consider installing secondary containment, such as berms, dikes, liners, vaults, and double-walled tanks.

### *Industrial Waste Management and Outside Manufacturing BMPs*

Stormwater runoff from areas where industrial waste is stored, treated, or disposed of can be polluted. Outside manufacturing activities can also contaminate stormwater runoff. Contaminants include toxic compounds, oil and grease, solvents, heavy metals, suspended solids, etc.

- Conduct a waste reduction assessment including: waste segregation and separation, process or equipment modification, closed-loop recycling, loss prevention and housekeeping, and training and supervision.
- Institute industrial waste source reduction and recycling.
- Prevent runoff and runoff from contacting the waste management area.
- Prevent contact with rain. Cover waste piles and use berms.
- Minimize runoff from land application sites.

#### *Outside Storage of BMPs*

Raw materials, byproducts or finished products, containers, and storage areas exposed to rain and/or runoff can contaminate stormwater.

- Cover or enclose materials. Store material indoors; use temporary coverings such as tarps.
- Minimize runoff by using berms, curbs, etc.

#### *Salt Storage Facilities BMPs*

Salt stored in piles may be lost by exposure to wind and precipitation. This loss should be minimized.

- Put salt under a roof.
- Use temporary covers.
- Enclose or berm salt transfer areas.

### **Site-Specific BMPs**

#### *Flow Diversion Practices*

Structures that divert stream flow, such as gutters, sewers, dikes, and graded pavement can be BMPs in two ways. They may channel stormwater away from industrial areas so pollutants do not mix with the stormwater. They may also carry pollutants directly to a treatment facility.

- Stormwater conveyances include channels, gutters, drains, and sewers.
- Diversion dikes, also called berms, block runoff from passing beyond a certain point.
- Graded areas and pavement allow runoff to flow in an organized direction.

### *Exposure Minimization Practices*

This group of BMPs addresses eliminating or minimizing the possibility of stormwater coming into contact with pollutants, hence reducing contamination of stormwater discharges. Structural and nonstructural alternatives are presented.

- Containment diking is temporary or permanent earth or concrete berms or retaining walls designed to hold spills.
- Curbing, like diking is a barrier that surrounds an area of concern. However, it is generally smaller-scale and cannot handle large spills.
- Drip pans are small depressions or pans used to contain very small volumes of leaks, drips, and spills.
- Collection basins, or storage basins, are permanent structures where large spills or contaminated stormwater is contained and stored before cleanup or treatment.
- Sumps are holes or low areas structured so liquid spills or leaks will flow down toward a particular part of a containment area. Often pumps are placed in a depressed area and are turned on automatically to transfer liquids away from the sump when the level of liquid gets too high.
- Covering is the partial or total physical enclosure of materials, equipment, process operations, or activities and can be temporary or permanent.
- Vehicle positioning is the practice of properly locating trucks or rail cars while transferring materials to prevent spills of materials onto the ground surface, which may then contaminate stormwater runoff.
- Loading and unloading by air pressure or vacuum can help minimize contact between stormwater and potential pollutants.

### *Mitigative Practices*

Mitigation involves cleaning up or recovering a substance after it has been released or spilled to reduce the potential impact of a spill before it reaches the environment. Mitigation generally is a second line of defense where pollution prevention practices have failed or are impractical.

- Sweeping is used to remove small quantities of dry solids and dry chemicals.
- Shoveling can be used to remove larger quantities of dry chemicals and solids as well as to remove wetter solids and sludge.
- Excavation is the removal of released materials by mechanical equipment such as plows or backhoes.
- Vacuum and pump systems are effective for cleaning up spilled or exposed materials.
- Sorbents are materials capable of cleaning up spills through the chemical processes of adsorption and absorption. The sorbents must be mixed with the spill or the liquid must be passed through the sorbent. Sorbents come in many forms from particles to foams.

- Gelling agents are materials that interact with liquids either physically or chemically (i.e., thickening or polymerization) to concentrate and congeal it to become semisolid.

#### *Other Preventive Practices*

This group includes a few easily implemented measures to limit or prevent exposure of stormwater runoff to contaminants.

- Preventive monitoring practices include the routine observation of a process or piece of equipment to ensure its safe performance. It may also include the chemical analysis of stormwater before its discharge to the environment. Examples include automatic monitoring systems, automatic chemical monitoring, and nondestructive testing.
- Dust controls for land disturbance and demolition areas are any controls that reduce the potential for particles being carried through air or water. Dust control includes: irrigation or sprinkling, minimization of denuded areas, wind breaks, tillage, and chemical soil treatments.
- Dust controls for material handling areas are controls that prevent pollutants from entering stormwater discharges by reducing the surface and air transport of dust caused by industrial activities. The following types of controls are included: water spraying, negative pressure systems, collector systems (bag and cyclone), filter systems, and street sweeping.
- Signs and labels identify problem areas or hazardous materials at a facility. They suggest caution, provide instruction, and organize materials.
- Security could help prevent an accidental or intentional release of materials to stormwater runoff as a result of vandalism, theft, sabotage, or other improper uses of facility property. Measures include routine patrol, lighting, and access control (signs, fencing, guards, etc.).
- Area control procedures involve practicing good housekeeping measures such as maintaining indoor or covered material storage and industrial processing areas. Other area control procedures include: brushing off clothing, stomping feet to remove material, use of floor mats, coveralls, etc.
- Vehicle washing removes materials such as site-specific dust and spilled materials and avoids spreading them.

#### *Sediment and Erosion Prevention Practices*

Industrial activities that have areas with a high potential for erosion require sediment and erosion prevention practices. Areas of high erosion potential are subject to heavy activity such that plants cannot grow. Other areas are: soil stockpiles, stream banks, steep slopes, construction areas, and any area where the soil is disturbed or stripped of vegetation and subject to erosion.

Among the ways to limit and control sediment and erosion are: leave as much vegetation onsite as possible, minimize the time soil is exposed, prevent runoff from flowing across disturbed areas, stabilize the disturbed soils as soon as possible, slow down the runoff flowing across the site, provide drainage ways for the increased runoff, and remove sediment from stormwater runoff before it leaves the site.

- Preserving existing vegetation or revegetating disturbed soil as soon as possible after construction is the most effective way to control erosion. Other common vegetative practices include:

preservation of natural vegetation; buffer zones; stream bank stabilization; mulching, matting, and netting; temporary seeding; permanent seeding and planting; sodding and chemical stabilization (spray-on vinyl, asphalt, or rubber).

- Structural erosion prevention and sediment control practices are also very effective. Structural practices used in erosion prevention and sediment control divert stormwater flows away from exposed areas, convey runoff, prevent sediments from moving offsite, and can also reduce the erosive forces of runoff waters. These practices can be either permanent or temporary measures. Typical practices include: interceptor dikes and swales, pipe slope drains, subsurface drains, filter fences, straw bale barriers, brush barriers, gravel or stone filter berms, storm drain inlet protection, sediment traps, temporary sediment basins, outlet protection, check dams, surface roughening, and gradient terraces.

### *Infiltration Practices*

Infiltration practices are surface or subsurface measures that allow for quick infiltration of stormwater runoff. Rapid infiltration is possible because the structures or soils used in these practices are very porous. Infiltration practices offer an advantage over other practices in that they provide some treatment of runoff, preserve the natural flow in streams, and recharge ground water. Many infiltration practices also can reduce the velocity of runoff so it will not cause damaging erosion. Another benefit is that infiltration reduces the need for expensive stormwater conveyance systems.

- Vegetative infiltration practices rely on vegetated soils that are well drained to provide storage for the infiltration of stormwater. Soils used for this practice generally have not previously been disturbed or compacted so that they more easily allow infiltration. Once vegetation has been planted, use of the area must be limited or the practice may not operate efficiently. Common methods include vegetated filter strips, grassed swales, and level spreaders.
- Infiltration structures are built over soils to aid in collection of stormwater runoff and are designed to allow stormwater to infiltrate into the ground. Maintenance activities are very important. Often, infiltration structures are used with other structures that pretreat the stormwater runoff for sediments, oil, and grease. Types of infiltration structures include infiltration trenches, porous pavements, concrete grids, and modular pavements.

## 8 MAINTENANCE BMPS

### Fertilizer Management

#### *Description*

Fertilizer management involves controlling the rate, timing, and method of applying fertilizer in urban areas. The intention of fertilizer management is to add just enough artificial nutrients to the soil so that healthy plant growth is maintained, while minimizing the potential risk of polluting surface water or groundwater. Fertilizer management will come in the form of social controls on homeowners' desires to maintain their property. Therefore, state and local regulations will have to be enacted to provide fertilizer management.

#### *Target Pollutants*

Fertilizer management will be directed at controlling the levels of phosphorous and nitrogen in urban stormwater runoff and can be directly correlated to the extensive application of fertilizers by the public. Therefore, by limiting the amount of fertilizer used by the public, the levels of phosphorous and nitrogen in urban runoff can be effectively reduced. The type and timing of application should be controlled also.

#### *Effectiveness*

Fertilizer management can be an effective practice for controlling nutrients from landscape areas. Significant nutrient loads can result from the over-application of lawn fertilizer in urban areas. Reducing the amount of fertilizer to the minimum needed for plant growth will effectively reduce the potential risk for surface or groundwater contamination. It will be difficult to quantify the benefits of fertilizer management, but proper management will reduce the availability of the pollutants associated with fertilizers.

#### *Planning Considerations*

Phosphorous is a major water quality concern because it is a primary cause of lake enrichment leading to excessive growth of aquatic plants and algae. The misuse or misapplication of phosphorous fertilizer can cause water quality problems. However, phosphorous fertilizers may be required to establish a healthy growth of vegetative cover. Phosphorous is essential to seedling germination and growth of new seedlings. If the seeding is sparse due to phosphorous deficiencies, the resulting erosion could cause sediment pollution, which carries a large nutrient load with it. In this case, the proper use of phosphorous fertilizer could actually reduce long-term nonpoint source pollution.

For new seedlings, phosphorous fertilizer should be incorporated into the soil during seedbed preparation, and the soil should be protected from erosion with proper erosion control practices. Existing landscape areas should be aerated with a coring machine before the fertilizer is applied, and phosphorous fertilizer recommendations should be based on soil test results. Some existing soil conditions may have naturally high levels of phosphorous due to the buildup of phosphorous from previous fertilizer applications. If the natural levels of phosphorous are high, the application of additional phosphorous fertilizer should be restricted; it may be possible to use alternative fertilizers that do not contain phosphorous.

Nitrogen is the fertilizer element that generally brings about the greatest response in plants. Nitrogen is found in soils in the form of ammonium ( $\text{NH}_4$ ), in the form of nitrate, and as a component

of organic matter. Ammonium is easily converted into nitrates, and nitrates are completely soluble and are not absorbed very well by soil particles. Therefore, nitrates will gradually be transported to the water table and will eventually lead to groundwater contamination. The potential risk of groundwater contamination will be greatest when excessive quantities of nitrogen fertilizer are applied to soil that is highly permeable. Nitrogen soil tests should not be used to determine application rates of nitrogen fertilizers due to the mobility of nitrate in most soils. Therefore, any local or state guidelines regulating the use of nitrogen fertilizers should be adhered to at all times.

## **Litter Control**

### *Description*

Litter control involves removing litter from streets and other surfaces before stormwater or wind moves it downstream to surface water bodies. The primary types of litter associated with urban nonpoint source pollution are lawn clippings and dead leaves. Therefore, controlling litter will prevent downstream pollution and improve the aesthetic value of the urban areas.

### *Target Pollutants*

A major source of phosphorous in urban stormwater runoff is associated with the disposal of lawn clippings and dead leaves. Removing leaves and lawn clippings from stormwater runoff before they enter downstream water bodies could significantly reduce phosphorous levels in surface waters. In addition to leaves and lawn clippings, other litter that should be controlled includes pet wastes, trash, oil, and chemicals. Most of these materials are organic and could create a high oxygen demand as they decay in water. Pet wastes are also a major source of bacteria in urban stormwater runoff.

### *Effectiveness*

The effectiveness of a litter control program will depend on the degree of public participation. A study to determine the effects of urban stormwater runoff on lakes found that phosphorous levels could be reduced by 30 to 40 percent when street gutters were kept free of leaves and lawn clippings.<sup>30</sup>

### *Planning Considerations*

The two categories of litter control programs are: source reduction and removal. The following recommendations have been made for source reduction programs:<sup>31</sup>

1. Litter containers should be conveniently placed and emptied frequently to prevent overflow.
2. Recycling programs should be promoted.
3. Public education programs should be developed since litter control programs depend on public support.

<sup>30</sup> J. Shapiro and H. Pfannkuck, "Interim Report No. 9" (Limnological Research Center, University of Minnesota, St. Paul, MN, 1973).

<sup>31</sup> G. Oberts, *Surface Water Management: Simplified Modeling for Watersheds*, Publication No. 10-83-130 (Metropolitan Council of the Twin Cities Area, St. Paul, MN, 1983).

Litter removal programs include refuse and leaf collection, street cleaning, and catch basin cleaning. Garbage collection could reduce the amount of trash that ends up in downstream water bodies. Removing trash from public areas is done primarily for aesthetic reasons, but it will also help to minimize the effects of pollution.

Leaf collection occurs at the local and private level; private collection of leaves will depend on the public commitment to collect and dispose of leaves. Educational programs that explain the environmental benefit of leaf collection to water quality could be helpful. Municipal leaf collection is usually accomplished by street sweepers. Municipal street sweeping can prevent a significant nutrient load from reaching receiving waters and can prevent storm sewer inlets from becoming clogged with debris.

## **Catch Basin Maintenance**

### *Description*

Catch basins are chambers installed in a storm sewer, usually at the curb, that allow surface water runoff to enter the storm drainage network. Many catch basins have a low area intended to retain sediments. By trapping coarse sediments, a catch basin will prevent trapped suspended solids from clogging the storm drainage systems or from being washed out into receiving water bodies. The primary disadvantage of catch basins is that they have to be cleaned out periodically to maintain their sediment trapping capabilities.

### *Target Pollutants*

Catch basins are effective for trapping coarse-grained sediments and large debris. In addition to reducing sediment loads, catch basin cleaning will also reduce oxygen demanding substances that may reach downstream surface water bodies.

### *Effectiveness*

Typical catch basins have been estimated to retain up to 57 percent of coarse sediments and 17 percent of equivalent BOD.<sup>32</sup> The sediment chambers in most catch basins have a capacity of 0.5 to 1.5 cu yd. The rate at which catch basins are filled, and the amount of material removed during different frequencies of cleaning, will vary greatly. If the drainage area of the catch basin has high sediment loads, the catch basin should be cleaned more often than catch basins in fairly stable areas. It is not possible to quantify the water quality benefits of catch basin cleaning, but cleaning does provide some benefits including the removal of pollutant loads from storm drains, the reduction of high pollutant concentrations during the initial period of storm events, and the prevention of clogging of the downstream storm drainage network.

## **Street Sweeping**

### *Description*

Street sweeping involves removing sediment, debris, and trash from urban streets, parking lots, and sidewalks using either a mechanical broom sweeper or a vacuum sweeper. If the materials are removed

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<sup>32</sup> Lager, J.A., et al., *Urban Stormwater Management and Technology: Update and User's Guide*, Report No. EPA-600/8-77-014 (U.S. Environmental Protection Agency, 1977), p 313.



from the streets where they are deposited, they will no longer be available to be carried in urban stormwater runoff. In most cases, the prime reason for street sweeping is for aesthetics and urban housekeeping rather than water quality benefits.

#### *Target Pollutants*

Street sweeping is most effective for removing coarse sediments, leaves, trash, and similar materials. In some cases, relatively high quantities of these materials could be delivered to a downstream body of water if the materials were not removed from street surfaces. The specific pollutants reduced by street sweeping include sediment, nutrients, and oxygen demanding substances.

#### *Effectiveness*

Street sweeping generally does not significantly benefit water quality.<sup>33</sup> In most cases, regular street sweeping actually resulted in negative effects on water quality, with concentrations of particulates increasing as much as 100 percent at several sites.<sup>34</sup> The reason for the increased concentrations are the result of the sweeper breaking sediment into finer particulates that are more readily detached and transported by stormwater runoff.

The dominant influence on the effectiveness of street sweeping appears to be the frequency of sweeping and the interval between storm events. Other influences are operator skill and the effectiveness of parking bans during sweeping operations, which make the sweeping as efficient as possible. Other factors include (1) total mass of the area to be swept, (2) efficiency of sweepers, and (3) local storm characteristics.<sup>35</sup>

#### *Planning Considerations*

Semiannual street sweeping operations are recommended to remove debris after spring snow melt and after leaves fall in the Autumn. Two types of sweepers are typically used: mechanical broom sweepers and vacuum sweepers. Vacuum sweepers are more effective for removing fine-grained sediments. Removing fine sediments is important because many pollutants are adsorbed on them. Vacuum sweepers have the disadvantage of being ineffective for cleaning wet street surfaces. Mechanical broom sweepers are effective at picking up large particulate matter, and they are effective on wet street surfaces. Although broom sweepers cost less to operate, one disadvantage of using them is that they generally create airborne dust during their operation, which may increase atmospheric loadings to a certain extent.

#### **Deicing Chemical Control**

##### *Description*

Tremendous amounts of deicing chemicals are used each winter on roadways, parking lots, and sidewalks. Sodium chloride is the primary chemical used. Proper application and storage of sodium chloride will help to reduce the chance of high chloride concentrations in runoff that may damage the environment.

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<sup>33</sup> USEPA "Street Sweeping for Control of Urban Stormwater Quality (Draft)," Water Planning Division (Washington, DC, 1982); USEPA, *Results of the Nationwide Urban Runoff Program*.

<sup>34</sup> USEPA, 1982.

<sup>35</sup> USEPA, 1982.

### *Target Pollutants*

Sodium chloride is the primary pollutant resulting from deicing. However, trace metals in stormwater runoff have also been associated with the use of sodium chloride as a deicing agent.<sup>36</sup> Other compounds are being studied as alternatives to traditional sodium chloride. One alternative is calcium magnesium acetate, which is less polluting and less corrosive.

### *Effectiveness*

It has been estimated that 80 percent of the environmental damage from deicing chemicals is caused by inadequate storage facilities. Proper storage practices can control sodium chloride pollution in stormwater runoff from storage stock piles. Preventing overapplication of sodium chloride will reduce quantities of chloride that will reach surface or groundwater. Virtually all sodium chloride used for deicing eventually enters surface or groundwater.<sup>37</sup> Therefore, any reduction that can be achieved by preventing overapplication of sodium chloride would reduce chloride pollutant levels by an equivalent amount.

### *Planning Considerations*

To prevent chloride from entering surface or groundwater, the following practices should be used at storage locations:

1. Any run-off from stockpiles should be contained.
2. All sodium chloride piles should be covered if not stored in a shed.

Sodium chloride pollution can be reduced by preventing over-application. This can be accomplished by properly calibrating equipment and monitoring the need for deicing chemicals. The second method is to limit sodium chloride application on low traffic areas and straight, level areas. Critical areas such as intersections, hills, and major roads will need higher levels of service.

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<sup>36</sup> J.L. Richards, and Associates and Labrecque, Vezina, and Associates, *Snow Disposal Study for the National Capital Area, Technical Discussion* (Committee on Snow Disposal, Ottawa, Ontario, 1973); G.L. Oberts, 1983.

<sup>37</sup> R. Pitt, *Characterizing and Controlling Urban Runoff Through Street and Sewerage Cleaning*, USEPA 600-52-85-038 (USEPA, Washington, DC, 1985).

## 9 SOIL EROSION AND SEDIMENT CONTROL BMPS

Construction site erosion results from the detachment and offsite transportation of soil particles and any pollutants adsorbed by the sediments. Construction site erosion occurs when adequate measures are not taken during land disturbance activities to prevent or contain soil erosion. The pollutants associated with construction site erosion are sediments, particulate organic solids, trace metals, nutrients, petroleum hydrocarbons, salts, bacteria, and litter. Even though construction site erosion tends to be short in duration, it contributes relatively large quantities of pollutants to stormwater runoff.

Soil stabilization measures provide protection from erosion by stormwater runoff. Vegetative covers can provide effective soil stabilization, but in many cases, the physical and biological environment surrounding the vegetation needs the extra stability and protection provided by surface contouring, emplacing stable materials, or structural control measures. Establishing a vegetative cover is a relatively inexpensive soil stabilization and stormwater management technique that will be ideal for most circumstances.

Stormwater management considerations will help manage concentrated flows of water that can lead to gully, stream, and channel erosion. Stormwater runoff is primarily affected by the surface topography of a given area and the soil characteristics of the sediments. Based on the combination of soil characteristics and drainage conditions for a given site, sediment control measures will provide for onsite management of sediment to prevent damage to adjacent properties and downstream waterways. Sediment control measures will not prevent the detachment of soil particles, but they will effectively trap sediments from being transported by stormwater runoff.

Appropriate land use and proper vegetative measures will be necessary for a good soil erosion and sediment control system. However, some vegetative applications and routine maintenance practices may not be adequate to handle severe sediment loads. Severe sediment loads will have to be addressed by engineering structures in conjunction with vegetative practices. Therefore, vegetative and land use practices are considered nonstructural BMPs, while anything else is considered structural BMPs. The following BMPs are some of the possible processes for soil erosion and sediment control that have been adopted by the Soil Conservation Service (SCS). If additional information on any of these BMPs is desired, refer to the *Field Office Technical Guide*. Another recent publication of interest is *Storm Water Management for Construction Activities*. It also presents a variety of background information.

### Nonstructural BMPs

- Permanent vegetation with seeding,
- Permanent vegetation with seeding,
- Temporary vegetation with seeding,
- Mulching for temporary and permanent seeding,
- Conservation cover,
- Conservation cropping sequence,
- Conservation tillage,
- Chemical stabilization,
- Buffer zones,
- Preservation of natural vegetation,
- Sod stabilization,
- Stream bank stabilization, and
- Dust control.

### Structural BMPs

- Temporary sediment basin,
- Temporary sediment trap,
- Silt fence,
- Straw bale sediment trap,
- Storm drain inlet protection,
- Floatation silt curtain,
- Temporary rock construction entrance,
- Diversions,
- Temporary diversion,
- Temporary right-of-way diversion,
- Stormwater conveyance channel,
- Subsurface drain,
- Temporary slope drain,
- Grade stabilization structure,
- Conduit outlet protection,
- Lot benching,
- Temporary stream crossing,
- Riprap,
- Structural streambank protection,
- Level spreader,
- Topsoiling,
- Sandbagging,
- Geotextiles, and
- Soil retaining measures.

In most situations a combination of structural and nonstructural BMPs should be used in highway and land development projects to reduce nonpoint source pollutant loading. In highway projects, diversion and filter structures, and mulches and temporary seeding will create an additional cost to the project, with estimates of \$1600/acre. The cost may appear to be high, but is far less than the cost for site restoration when damage is done to downstream water bodies.

## 10 FORESTRY BMPS

Forestry related activities have long been recognized as having the potential to cause water pollution via nonpoint sources. The types of problems related to forestry activities include generation of sediment from roads and landslides, loss of shade from removing the canopy over streams, woody debris jams from poorly managed logging slash, increased channel erosion, and increased stream bedload sediments. This can result in:

- Suspended and bedload sediments,
- Turbidity,
- Woody material accumulation on bottoms,
- Temperature increases, including potential temperature-induced effects on development of salmonid smolts and changes in aquatic communities,
- Loss of important stream structural habitat provided by large woody debris from fallen trees, especially from conifers,
- Concentration and channelization of flows entering wetlands from road drainage systems and drainage of wetlands due to mechanical site preparation,
- Loss of trout, salmon, and other anadromous fish species,
- Nutrient accumulations from forest fertilizer misapplications or spills, and
- Toxic pollutant accumulations from misapplications of pesticides or spills.<sup>38</sup>

States with large forestry programs have identified BMPs for silviculturally related nonpoint source water quality problems. The North Carolina Department of Environment, Health, and Natural Resources, for example, has prepared a reference document for silvicultural BMPs entitled *Forest Practices Guidelines Related to Water Quality*, which is summarized as follows:<sup>39</sup>

1. Properly design and place access roads, skid trails, and loading areas on forestland.
  - a. Avoid streambanks and channels except when crossing streams.
  - b. Install water management structures and techniques.
  - c. Stabilize bare soil areas.
  - d. Prevent steep slopes on roads and trails.
2. Designate streamside management zones that are undisturbed strips of vegetation parallel to and adjacent to the stream channels.
3. Avoid placing debris in stream channels.
4. Use practices that minimize soil exposure when reforesting.

<sup>38</sup> USEPA, *Proposed Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters* (USEPA, Washington, DC, 1991).

<sup>39</sup> North Carolina Department of Environment, Health, and Natural Resources, Water Quality Technical Report 89-02, *Forest Practices Guidelines Related to Water Quality* (April 1989).

5. Use environmentally safe procedures when applying chemicals in forested areas.

6. Train forestry personnel in NPS pollution control methods.

The USEPA, in suggesting guidance for coastal zone areas, also addresses forestry BMPs including costs, components, specifications, and effectiveness.<sup>40</sup> They suggest:

- Identify and designate streamside special management areas,
- Identify and designate wetland special management areas,
- Plan and design a transportation system,
- Construct/reconstruct a transportation system,
- Road management,
- Timber harvest planning,
- Landings and groundskidding of logs,
- Landings and cable yarding,
- Mechanical site preparation,
- Prescribed fire,
- Mechanical tree planting,
- Revegetation of disturbed areas,
- Stream protection for pesticide and fertilizer projects, and
- Petroleum products pollution prevention.

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<sup>40</sup> USEPA, 1991.

## 11 AGRICULTURAL BMPS

The Rural Clean Water Program (RCWP) has listed a number of BMPs for agricultural nonpoint source pollution. They are presented below and represent appropriate methods for a rural environment with the primary focus on agriculture.<sup>41</sup>

### **Permanent Vegetative Cover**

Lifespan: minimum of 5 years.

Components:

- Fencing,
- Grasses and legumes in rotation,
- Pasture and hayland management,
- Pasture and hayland planting,
- Proper grazing use,
- Range seeding, and
- Planned grazing systems.

### **Animal Waste Management System**

Lifespan: minimum of 10 years.

Components:

- Waste management system,
- Critical area planting,
- Dike,
- Waste treatment lagoon,
- Diversion,
- Fencing,
- Filter strips,
- Grassed waterway or outlet,
- Waste storage pond,
- Irrigation system, sprinkler,
- Irrigation system, surface and subsurface,
- Subsurface drain, field ditch,
- Surface drain, main or lateral, and
- Waste utilization.

### **Stripcropping Systems**

Lifespan: minimum of 5 years.

Components:

- Obstruction removal,
- Stripcropping, contour,
- Stripcropping, field, and
- Stripcropping, wind.

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<sup>41</sup> USEPA, *Rural Clean Water Program: Lessons Learned from a Voluntary Nonpoint Source Control Experiment* (USEPA Washington, DC, 1990).

**Terrace System**

Lifespan: minimum of 10 years.

Components:

- Obstruction removal,
- Terrace,
- Subsurface drain, and
- Underground outlet.

**Diversion System**

Lifespan: minimum of 10 years.

Components:

- Dike,
- Diversion,
- Obstruction removal,
- Subsurface drain, and
- Underground outlet.

**Grazing Land Protection System**

Lifespan: minimum of 10 years.

Components:

- Pond,
- Fencing,
- Pipeline,
- Pond sealing or lining,
- Spring trails and waterways,
- Stock trails and waterways,
- Trough or tank, and
- Well.

**Waterway System**

Lifespan: minimum of 10 years.

Components:

- Fencing,
- Grassed waterway or outlet,
- Lined waterway or outlet, and
- Subsurface drain.

**Cropland Protective System**

Lifespan: must be recommended by county and state Agricultural Stabilization and Conservation (ASC) committees and approved by Administrator, ASCS, if less than 5 years.

Components:

- Conservation cropping system,
- Cover and green manure crop, and
- Field windbreaks.

**Conservation Tillage Systems**

Lifespan: must be recommended by county and state ASC committees and approved by Administrator, ASCS, if less than 5 years.

Components:

- Conservation cropping system,
- Conservation tillage system,



Contour farming,  
Crop residue use,  
Land smoothing, and  
Stubble mulching.

**Stream Protection System**

Lifespan: minimum of 10 years.

Components:

Channel vegetation,  
Fencing,  
Filter strip,  
Streambank protection, and  
Tree planting.

**Permanent Vegetative Cover on Critical Areas**

Lifespan: minimum of 15 years.

Components:

Critical area planting,  
Fencing,  
Field Borders,  
Filter strip,  
Livestock strip,  
Livestock exclusion,  
Mulching,  
Sinkhole treatment,  
Spoilbank spreading,  
Tree planting, and  
Well plugging.

**Sediment Retention, Erosion, or Water Control Structures**

Lifespan: minimum of 10 years.

Components:

Sediment basin,  
Dike,  
Fencing,  
Grade stabilization structure,  
Structure for water control, and  
Water and sediment control basin.

**Improving an Irrigation and/or Water Management System**

Lifespan: minimum of 10 years.

Components:

Irrigation water conveyance,  
Pipeline,  
Irrigation system, drip,  
Irrigation system, sprinkler,  
Irrigation system, surface and subsurface,  
Irrigation system, tailwater recovery,  
Irrigation water management,  
Irrigation land leveling, and  
Structure for water control.

**Tree Planting**

Lifespan: minimum of 10 years

**Components:**

- Cover and green manure crop.
- Fencing,
- Proper woodland grazing, and
- Tree planting.

**Fertilizer Management**

Lifespan: must be recommended by COC and STC and approved by the Administrator, ASCS, if less than 5 years.

**Components:**

- Fertilizer management, and
- Waste utilization.

**Pesticide Management**

Lifespan: must be recommended by COC and STC and approved by the Administrator, ASCS, if less than 5 years.

**Woodland and Access Road Stabilization**

Lifespan: minimum of 10 years.

**Water Quality Improvement through Woodland Improvement**

Lifespan: minimum of 10 years.

The USEPA presents a number of management measures under the following categories: erosion and sediment control, confined animal facility management, nutrient management, pesticide management, grazing management, and irrigation water management.<sup>42</sup> Options are discussed for each category including information about applicability, associated pollutants, best economically achievable results, management practices, pollutant reduction effectiveness (preliminary), cost (preliminary), and operation and maintenance information.

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<sup>42</sup> USEPA, 1991.

## 12 SUMMARY

This report presented an overview of BMPs with potential for implementation throughout the Army. Applicable regulations and legislation were reviewed and BMP selection criteria were examined. A number of BMPs were examined in detail, providing information appropriate for an Army decisionmaker or engineer to determine the local applicability of the BMP. Alternative techniques for urban stormwater management, both structural and nonstructural, were described in detail. Practices for forestry, agriculture, and sediment control were described in a more cursory manner.

NPS pollution is a major pollution concern of the nation and as point sources have become more controlled, NPS pollution is receiving increased Federal attention. Tremendous resources will be required to remove and prevent these major contaminant sources from polluting the nation's surface and groundwaters. Applying the BMPs discussed in this report will help the Army comply with legislative and regulatory requirements, and be good neighbors and stewards of valuable resources.

### METRIC CONVERSION TABLE

1 acre	=	0.404 hectare
1 ft	=	0.305 m
1 gal	=	3.78L
1 in	=	2.54 cm
1 cu yd	=	0.7646 m <sup>3</sup>

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## ABBREVIATIONS

AMC	Army Materiel Command
AR	Army Regulation
ASC	Agricultural Stabilization and Conservation
BAT	Best Available Technology
BCT	Best Conventional Pollutant Control Technology
BMP	Best Management Practice
BOD	Biological Oxygen Demand
CCC	Commodity Credit Corporation
CFR	Code of Federal Regulations
COD	Chemical Oxygen Demand
CSO	Combined Sewer Overflow
CWA	Clean Water Act
CZARA	Coastal Zone Reauthorization Amendments
DO	Dissolved Oxygen
DoD	Department of Defense
ECARP	Environmental Conservation Acreage Reserve Program
FACTA	Food, Agricultural, Conservation and Trade Act of 1990
FR	Federal Register
FSA	Food Security Act of 1985
ITAM	Integrated Training Area Management
MEP	Maximum Extent Practicable
NOAA	National Oceanic and Atmospheric Administration
NOI	Notice of Intent
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint source pollution
NURP	Nationwide Urban Runoff Program
POLs	Petroleum, Oils and Lubricants
POTWs	Publicly Owned Treatment Works
RCWP	Rural Clean Water Program
SCS	Soil Conservation Service
TN	Technical Note
TSS	Total Suspended Solids
USACERL	U.S. Army Construction Engineering Research Laboratories
USACPW	U.S. Army Center for Public Works
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
WQMP	Water Quality Management Plan
WWTP	wastewater treatment plant

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